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INFLUENCES OF VEGETATION AND WATERSHED TREATMENTS ON RUN-OFF, SILTING, AND STREAM FLOW

A Progress Report of Research

Prepared by the

Forest Service and
the Soil Conservation Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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A PROGRESS REPORT OF RESEARCH

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SOIL, VEGETATION, AND WATER FLOW

In the course of some 30 years, the Department of Agriculture and other agencies have conducted studies and investigations of the effects of various types of land use treatment on run-off and water-flow retardation and soil-erosion prevention. Most of the early work was restricted to forested lands. In 1929, when soil-erosion experiment stations were established in the several types of farming regions, the scope of the Department's investigations was widened to include studies on agricultural land.

These studies have gradually led to an understanding of some of the basic relationships between land use and run-off, debris deposition, the shoaling of stream channels, silting of reservoirs, storm flows, and other phenomena that have followed logging, cultivating, burning, and grazing. They have revealed something of the nature

of the change in water behavior that ensues from modifications in the land cover with man's use of the land. However, it is an open question whether determination of the influence of watershed conditions on stream regulation will ever be reduced to an exact science. There are too many complex biological and physical factors involved in water-land relationships that cannot be precisely weighed with present techniques. Even the more precise engineering calculations have their limitations in dealing with run-off and stream flow.

The idea of doing work on land to retard run-off and curb erosion in aid of flood control is not new. In Europe, many years ago, watershed improvement programs became firmly established as parts of general flood control programs. Application of this principle has long been advocated in the United States. Congress, in fact, first recognized the need for watershed protection in 1911, when it passed the Weeks Forest Purchase Act authorizing the Secretary of Agriculture to take certain steps toward "regulating the flow of navigable streams."

In 1936 Congress recognized flood control as an end in itself and a public objective independent of benefits for navigation, forestry, or soil conservation. The Flood Control Act of June 22, 1936, authorized a coordinated land-use and water-regulation program for flood control, and called upon two departments of government, War and Agriculture, to integrate their efforts. The act places responsibility for improving rivers and waterways for flood-control and allied purposes in the War Department (where it has always resided) and charges the Department of Agriculture to undertake works and measures for run-off and water-flow retardation and soil-erosion prevention on the watersheds to complement the works of the War Department.

This bulletin is being published as the first survey reports authorized under this act are being completed by the Department of Agriculture. These surveys serve as a basis for operations.

The results of research on land-water relationships have been reported bit by bit, as each experiment progressed to a point that conclusions could be drawn. The literature on the subject therefore covers a period of many years, and much of it is no longer available. The purpose of this publication is to gather the outstanding research bearing on the subject of water-flow retardation and place it between one set of covers, discarding the reports on which subsequent research with improved techniques has cast doubt, or in which conclusions were too broadly drawn or results given too wide an application. It is presented as a summary of progress in research as an aid to a fuller understanding of the effects of land-use measures on run-off retardation and erosion prevention. In most instances the summary covers a period up to the year 1938. Since 1938 research in this field has advanced at a rate greater than in any previous period. As summaries and interpretations of the data are completed, they will be published. It was not deemed advisable to delay publication of a summary of the earlier work in view of the fact that the Department now has assumed a share of the responsibilities for flood-control operations.

The last section outlines very briefly the research now under way in the Department that bears directly upon the effects of vegetation

and land-use practices on run-off retardation and soil-erosion prevention.

The Water Cycle

So far as man knows, the total quantity of water existing on the earth does not vary over long periods of time, although the forms and locations of water are constantly changing. In general, however, earth waters have a natural circulation known as the hydrologic cycle, shown diagrammatically in figure 1. The steps that make up this cycle may be outlined briefly as follows:

1. The atmosphere absorbs water from all exposed surfaces; i. e., from the oceans, lakes, rivers, the land—even from falling raindrops. This type of atmospheric absorption is called evaporation. The

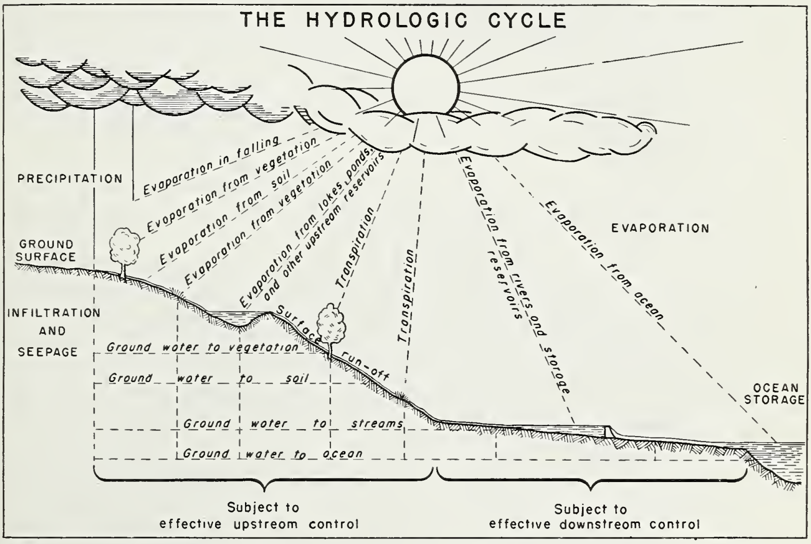

Figure 1.—Earth waters have a natural circulation known as the "hydrologic cycle."

atmosphere also absorbs water drawn from ground storage and released through vegetation, a process known as transpiration. The quantity of water removed from inland areas through evaporation and transpiration ranges from about 50 to 95 percent and averages approximately 70 percent of the precipitation on such areas.

2. Air laden with moisture may move for great distances before coming in contact with bodies of air sufficiently cool to condense the moisture and precipitate it in the form of rain or snow. Dew is also a form of precipitation.

3. The precipitated water, when it strikes the surface of the land, is usually absorbed by the soil. The entrance of water into the soil is called infiltration. When the water content of this surface soil layer has reached a point where additional water can no longer be held against the pull of gravity, this surplus penetrates to underground strata of soil, gravel, or porous rock. This downward move-

ment of water is known as percolation or seepage. The water stored temporarily or indefinitely in the substrata is called ground water. The surface of this underground reservoir is the water table. Except in closed basins, ground water eventually is discharged at some lower level through springs and seeps.

4. When the rate of precipitation exceeds the rate of absorption and infiltration, the excess water flows off at or near the surface of the ground directly into creeks and rivers, and thence into the sea. This surficial run-off is often called storm flow and together with the discharged ground water or deep seepage flow makes up the total surface run-off. Thus, infiltration and run-off are related. Surficial or storm flow varies according to the combination of such factors as intensity and duration of precipitation and the infiltration capacity of the soil. Infiltration varies according to numerous factors which are determined by cover conditions and the characteristics of the soil and substrata. The surface soil and its cover have two chief regulatory functions with respect to infiltration: First, they act like a sieve and separate run-off from infiltration; and second, the topsoil does not permit water to pass downward to underground storage until the topsoil reservoir is filled beyond its ability to hold water against the pull of gravity.

Water exposed on the surface of the oceans, lakes, rivers, and land is again absorbed into the atmosphere. This natural circulation continues indefinitely.

In water conservation and run-off retardation, the chief concern is with that part of the hydrologic cycle related to precipitation falling on the earth's surface and its movement and disposition thereafter. However, it must not be lost sight of that the hydrologic cycle is continuous, so that modification of any one part may influence another. Thus evaporation, transpiration, precipitation, absorption, and infiltration all influence storm flow, and if one factor is affected some one or some combination of the other factors will be influenced.

The factors of the hydrologic cycle that man can expect to manipulate most readily are infiltration, absorption, and evapo-transpiration processes, the last through his control of the plant cover. To the extent that absorption and infiltration can be increased, surface run-off and storm flow can be reduced. It is here that watershed control measures designed to increase soil cover and the content of organic matter of soils, and to effect other changes which retard run-off, may be expected to operate. The upstream control measures are intended, in short, through vegetation, proper land-use practices, water-retarding devices, etc., to maintain or increase the utilization of the capacity of the soil as a reservoir.

Land Storage of Water

Obviously if the outer surface of the earth were a solid and impervious mass a torrent would rush from each watershed after every heavy rain. Floods, under such conditions, would be of such magnitude and such frequent occurrence as to prevent the establishment of land life. The earth's surface, however, is a relatively porous body capable of absorbing and holding a tremendous quantity of water.

The surface mantle of the earth is commonly divided into two zones with reference to how and where water is held. This is illustrated in figure 2. These are the zone of aeration and the zone of saturation. The latter (ground-water supply) will be discussed later. The zone of aeration, which is the uppermost of the two, is divided into three principal parts: (1) The belt of soil water, (2) the intermediate belt, and (3) the capillary fringe. The belt of soil water lies nearest the surface and moisture may be lost from it through transpiration by plants, or through evaporation after rising to the surface by capillary action. The capillary fringe is the zone that lies immediately above the water table and contains water drawn up from the ground water by capillary action. Between these lies the intermediate belt, its thickness depending, of course, on the depth to the water table. An intermediate belt does not exist where the water table is sufficiently close to the surface to cause contact between the capillary fringe and the belt of soil water.

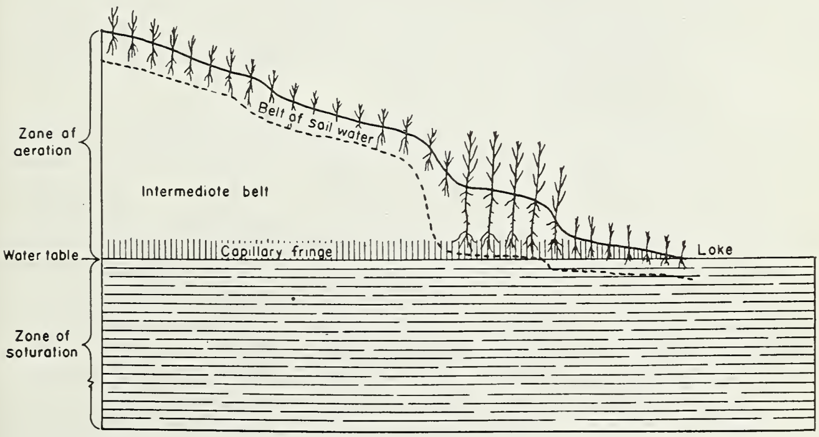

FIGURE 2.—Diagrammatic illustration of zones and belts of soil and ground water.

The water to be found in the zone of aeration is usually referred to as suspended subsurface water or vadose water. This is subdivided into soil water, intermediate vadose water, and fringe water. All suspended subsurface water is held by molecular attraction and when this attraction is less than the pull of gravity the water moves downward into the next lower belt until finally it reaches the water table.

The depth of the soil water belt is determined by soil characteristics and the type of vegetal cover. The thickness of the capillary fringe is determined by rock or soil characteristics.

With only rare exceptions all forms of underground water are supplied downward from the surface. Hence the quantity of underground water is dependent on the quantity of precipitation and the infiltration capacity of the surface soil and on percolation through the underlying strata. Although the ground-water phases of land storage are very important in the economy of water, this publication deals chiefly with the soil as a reservoir for water, meaning the

entire zone of aeration, pointing out those factors which will increase infiltration and its water holding capacity. The difference between the moisture content of the zone of aeration at the beginning of heavy or prolonged rainfall and nearly complete saturation of this zone is available as an equalizing reservoir for the retardation of water flow, provided the conditions of cover, soil, and other surface factors are conducive to maximum absorption and infiltration and the underlying strata are conducive to maximum percolation.

Ground-Water Storage

Ground water or phreatic water is commonly considered that part of the subsurface water which occurs below the zone of aeration, or more specifically, in the geologic term, the zone of saturation. It has been pointed out that the surface layers of the earth are for the most part a porous rather than a continuous mass. Likewise, the subsurface layers, composed of many different types of rock or soil material formations, are seldom, if anywhere, a solid mass (*40*).[1] Within the numerous open spaces or interstices of this unconsolidated material is temporarily stored the ground water that is partially recovered through springs and wells.

The porosity of rocks varies according to the differences in the minerals of which they are composed and the geologic processes under which the rocks were formed or later modified. The porosity of uncemented strata is influenced by the texture of the material and by the shape and arrangement of the aggregates. In general the porosity of ground-water zones ranges from a fraction of 1 percent in strata of solid rock with a few cracks or interstices, up to 50 percent or more in uncemented sedimentary deposits rather loosely compacted. A porosity of less than 5 percent may be considered as small and one greater than 20 as large.

The depth at which ground water occurs varies widely throughout the country. Meinzer (*40*) reports an average depth to the water table of 37 feet, based on data from 28,797 wells. He qualifies this, however, by explaining that, since wells are more numerous where the depth to the water is not so great, the actual average depth to water will average more than 37 feet. In some of the arid portions of the West mine shafts have been sunk to around 2,000 feet before reaching water. These are extreme cases.

High water tables are not always confined to humid parts of the country. Bryan (*16*) reports an average depth to water table of less than 25 feet for 80 percent of the Sacramento Valley in California.

At great depths pressure becomes so great as practically to obliterate pore space. The character of the rock and other strata will of course determine the relationship existing between pressure and pore space. Free water has been found at depths of more than 6,000 feet, but generally 3,000 feet is about the lower limit at which ground water may be expected to occur.

The steady flow of streams and the maintenance of natural lake levels is dependent on ground water.

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[1] Italic numbers in parentheses refer to Literature Cited, p. 76.

By the extent to which infiltration can be increased surficial run-off will be decreased. Moreover, throughout large areas of our country, water for human as well as for livestock consumption comes from the ground-water supply. During periods of protracted drought there is no other source of water in large areas, and the drain on the ground-water supply during such periods is often great. Ground water is so vital to man's existence that its importance should not be underestimated. In building up and maintaining this important resource, every practical measure should be utilized.

Character of Flood-Producing Rains

The extent and severity of a flood is principally a reflection of the characteristics of the storm producing it. The variation in time and from place to place of the intensity, duration, and area of the storm largely determines the rate of run-off and hence the rate of concentration of discharge waters. Other factors such as vegetation, slope, presence or absence of snow cover, condition of the soil, etc., cannot be neglected, but it is the storm itself which merits preeminent consideration.

Studies conducted by the Soil Conservation Service with the cooperation of the Weather Bureau and the Works Progress Administration have yielded information regarding rainstorm morphology which can usefully be employed in the initiation of safeguards against flood damage and in flood forecasting. These investigations carried out at the Oklahoma Climatic Research Center (*50*) and Muskingum Climatic Research Center (*51*), have for the first time made available detailed rainfall maps showing discrete and cumulative precipitation at short intervals throughout a storm. Analysis of these maps and records demonstrate that there are, descriptively, two principal types of storms: (1) Local, intense showers of short duration and characterized with large intensity variations within a small area; and (2) general storms that produce a more homogeneous rainfall pattern and which may be of several days' duration. Combinations of these two primary storm types may occur, so that not infrequently there are superimposed on a general storm one or more local storms of high intensity and limited areal extent.

Serious floods on large watersheds, such as that on the Brazos in 1898, on the Muskingum and the Miami in 1913, and in New England in 1936, are invariably associated with general storms including one or more centers of high intensity. Such storms may produce simultaneous precipitation over an area as large as 400,000 square miles (*52*) may last several days, and at the centers of maximum intensity not uncommonly yield 24-hour rainfall amounts as great as 4 inches in the Ohio Basin and 12 inches in the Gulf region.

The type of synoptic situation which accounts for many of the major floods is illustrated by that producing the flood of January-February 1937 in the Ohio Basin (*32*). In this instance a polar front remained virtually stationary for several days along, the western flank of the Appalachian Mountains while fresh, moist, tropical air continued to ascend over the colder air to the north and west and produced widespread and continuous precipitation. Waves

along the front and convectional disturbances produced several centers of high precipitation intensity both along and back of the front.

The rainfall pattern thus produced was therefore not simple and homogeneous as it would be in an "ideal" warm-front storm but rather yielded marked variations in precipitation throughout the storm area.

It may be seen from this example that duration is a factor of great importance in storms producing widespread floods. In floods on small watersheds, however, rainfall intensity becomes the most critical factor and storms lasting only a few hours may produce disastrous results. Such local storms are either convectional or frontal and produce simultaneous precipitation over only a few hundred square miles. One or more centers of high intensity exist, and where these centers occur at or near the center of a small watershed run-off rates are high and floods occur. Such an intensity center generally migrates at rates of from 15 to 25 miles an hour and by moving down a watershed greatly increases the rate of discharge. Precipitation rates vary from region to region; in the arid West 1.5 inches depth in an hour is not excessive, while falls of 3 inches depth in an hour occur with like frequency in the southeastern United States.

In both the general storms which produce widespread floods and in the local ones that endanger small watersheds, the precise rainfall pattern and the way in which this varies through time is of critical import. In either case, the rate of concentration of surface waters is largely a reflection of the location of the centers of high precipitation and the rate and path of storm migration. Such meteorological elements as these must be considered by the engineer in calculating what rates of discharge are to be expected in any given basin over a given period of years. It is necessary to think of rainfall patterns, changing with time, and which can be superimposed on a watershed in a great variety of ways, some of which may not even yield excessive run-off, while others may produce major flood catastrophes.

FACTORS AFFECTING INFILTRATION

Soil Porosity

Soil porosity may be defined as the percentage, by volume, of the soil that is unoccupied by solid particles. This space will of course be occupied either by air or by water. As additional water enters this space, the displaced air is forced out either through the surface or down into the underground water stream. Investigations show that the quantity of soil air which can be displaced by water will vary with the physical and chemical characteristics of the soil. Water may, in certain soil types, occupy approximately 90 percent of the pore space (*41*).

Some idea of the water-holding capacity of soils may be obtained from the data presented in table 1 showing the porosity of three representative and extensive soil types and the amount of water which these soils theoretically would hold if all the pore space were occupied by water.

TABLE 1.—*Porosity of 3 representative soils* [1]

Soil type and location	Depth of sample	Porosity (by volume)	Calculated maximum possible water storage of surface 3 feet of soil [2]
	Inches	*Percent*	*Inches*
Vernon fine sandy loam, Guthrie, Okla	(3)	43.3	14.4
	2½	41.5	
	8	41.7	
	22	39.4	
	38	40.2	
Muskingum silt loam, Zanesville, Ohio	(3)	48.1	16.2
	3½	45.1	
	9	47.8	
	17	45.5	
	32	31.3	
	54	32.7	
Marshall silt loam, Clarinda, Iowa	(3)	55.9	20.7
	6½	56.4	
	18½	60.3	
	32½	58.7	

[1] From U. S. Dept. Agr. Technical Bulletin 430 (*41*).
[2] The figures under this heading were calculated by Dr. Middleton but not included in the publication.
[3] Surface.

The texture of the soil as well as the shape and arrangement (structure) of the soil particles have a very definite influence on porosity and infiltration capacity. Fine-textured soils have a greater total porosity than coarse-textured soils. However, unless the soil possesses a highly granular structure, film friction causes water to move more slowly through fine-textured soils.

ORGANIC MATTER CONTENT OF SOIL

It is common knowledge that organic soils are more highly absorptive of water than mineral soils. Repeated tests reveal a very striking correlation between the quantity of humus present in a soil and its water-holding capacity. The addition of organic matter to soils deficient in this important constituent improves their structure, with the possible exception of certain highly alkaline soils, making them more permeable to water and increasing their water-holding capacity. The more stable portion of the humus (partially decomposed organic matter) helps to bind the soil particles and aggregates, bringing about a crumb or granular structure, and helps to eliminate puddling.

The superior physical condition of forest soils (fig. 3) has been demonstrated by experiment (*2*). Samples of the upper 9 inches of soil under several old-growth stands in oak-hickory and other hardwood types in the Ohio Valley were found to be 13 percent lighter at oven dryness than equal volumes of soil from adjacent cultivated fields and ill-managed pastures—indicating more pore space in the forest soils. At a 3-inch depth, 14 times as much water was absorbed per minute by the forest as by the field soil; and at a 1-inch depth, over 50 times as much.

Favorable soil porosity was found to return to old fields after forest planting. At 1-inch depth, the average rate of absorption in a 17-year-old plantation was 107 cc. per minute, as contrasted to only 8 cc. in an open adjacent field.

The results of a series of tests of the absorptive capacity of cherty and sandy soils in northern Arkansas and on yellow silt loam soils in southern Illinois are given in table 2.

TABLE 2.—*Rate of water absorption per second, per square foot of soil for three soil types under different site conditions*

Soil type and locality	Site conditions	Volumes of water absorbed per second [1] on application of the—			
		First liter	Second liter	Third liter	Fourth liter
		Cubic centimeters	*Cubic centimeters*	*Cubic centimeters*	*Cubic centimeters*
Yellow silt loam, Illinois	Undisturbed oak woods	21.83	23.36	22.78	21.23
	Burned oak woods	7.60	4.63	3.40	2.64
	Poorly managed pasture	2.52	1.34	1.01	.86
Cherty silt loam, Arkansas	Undisturbed oak woods	55.87	44.87	38.76	32.05
	Burned oak woods	14.25	9.78	6.12	5.10
	Poorly managed pasture	17.73	10.47	6.16	4.74
	Old-field pine woods	53.19	35.21	21.10	14.71
	Poorly managed pasture	12.32	7.66	8.04	6.37
Sandy soil, Arkansas	Undisturbed oak woods	64.10	46.08	40.00	30.50
	Poorly managed pasture	24.33	16.84	14.35	12.92

[1] 4 successive applications of water were made.

The data show that in the Illinois silt loam soils there is a great decrease in the water-absorptive capacities due to loss of organic matter as a result of severe fires on forest land and of mismanagement and trampling of pastured soils as compared with the undisturbed woods. In the case of the latter, the rate of absorption, for each successive liter of water applied, remained relatively constant throughout the test, whereas in the case of burned woods and pastured soils,

FIGURE 3.—The superior physical condition of forest soils is apparent. Their superior permeability has been demonstrated by experiment.

the rate of absorption diminished with each application. For both burned woods and pastured soils, the rate of absorption of the fourth liter of water was only about 35 percent that of the first. This decrease in water absorption can be explained by the compaction of bare surface soil that occurs during rainfall and by the sealing of the soil pores. The porosity of the forest soil, which is preserved by the protective covering of leaf litter, is greatly diminished when the litter is destroyed by fire or by grazing.

How great an effect organic matter, although an unimportant fraction by weight in most soils, has on the water-holding capacity of the soil is illustrated by the results given in table 3. These data were obtained on a sandy soil of granitic origin supporting ponderosa pine in Idaho. About 200 samples of the soil were taken to a depth of 4 inches from openings, some large and some small, in a virgin forest. The condition of the vegetation refers primarily to the forage cover, the deterioration of which is the result of overgrazing.

TABLE 3.—*Water holding capacity of surface soil of granitic origin under a ponderosa pine stand in Idaho as related to organic matter content*[1]

Condition of vegetation	Organic matter	Water-holding capacity
	Percent	*Percent*
Good (nearly original condition)	10.5	81
Intermediate (considerable deterioration)	4.8	55
Poor (bad deterioration, soil usually gullied)	2.4	44

[1] Studies by George Stewart, Intermountain Forest and Range Experiment Station.

That organic matter is nearly 5 times as influential as moisture content and, for the conditions covered, about 3½ times as influential as soil texture in determining the rates at which the granitic soils absorbed surface water has been clearly demonstrated on the Boise National Forest in Idaho. A determination was made of the rate of surface absorption by each of 108 carefully selected 1-square-foot plots entirely devoid of vegetation. Then the plots were classified on the basis of laboratory analyses of surface-inch soil samples according to soil texture, organic matter, and moisture content. Tables 4 and 5 show the results of the analyses. These investigations afford statistical evidence of the value of organic matter in reducing run-off through facilitating the absorption of surface water by the soil. While experimental results of this nature cannot be applied directly to large areas, they clearly demonstrate the significance of differences that exist in rates of absorption, and the effectiveness of good cover when compared with poor cover. The value is thus indicated of maintaining an adequate plant cover on critical watersheds and applying such practices as plowing under green-manure crops, adding animal manure, growing legumes, etc., on tilled lands in order to make greater use of the reservoir capacities of the soil.

TABLE 4.—*Water absorbed per hour by soils of varying texture, organic content, and moisture content*[1]

Soil texture	Organic-matter content, low (−2 percent)			Organic-matter content, medium (2–5 percent)			Organic-matter content, high (5 percent +)		
	Dry, −5 percent	Moist, 5–20 percent	Wet, 20+ percent	Dry, −5 percent	Moist, 5–20 percent	Wet, 20+ percent	Dry, −5 percent	Moist, 5–20 percent	Wet, 20+ percent
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Fine (40 percent silt and clay)	1.75	1.55	0.94	4.22	3.90	3.13	9.63	7.44	6.92
Medium (30–40 percent silt and clay)	2.08	1.54	1.33	5.63	4.57	4.11	9.89	8.51	7.79
Coarse (30 percent silt and clay)	2.43	1.84	1.58	6.88	6.00	5.42	15.00	12.25	10.89

[1] Studies by C. Kenneth Pierce, Intermountain Forest and Range Experiment Station. Moisture given as percentage of water-holding capacity.

TABLE 5.—*Influence of organic matter, moisture content, and soil texture on the mean rate of water absorption*[1]

Organic-matter content		Moisture content		Soil texture	
Quantity	Absorption per hour	Quantity	Absorption per hour	Texture	Absorption per hour
	Inches		*Inches*		*Inches*
Low (under 2 percent)	1.67	Dry (under 5 percent)	6.38	Fine (40 percent silt and clay).	4.38
Medium (2 to 5 percent.	4.86	Moist (5 to 20 percent)	5.29	Medium (30 to 40 percent silt and clay).	5.05
High (over 5 percent)	9.81	Wet (over 20 percent)	4.67	Coarse (30 percent silt and clay).	6.93

[1] The data in this table summarize those given in table 4. Moisture given as percentage of water-holding capacity.

Plant Roots Form Channels

Channels left by decayed roots also perform an important function in soil infiltration and storage of water. These roots ramify through the soil in an amazingly intricate network, the denseness of the roots depending on the type and denseness of the vegetation. Near the surface this network is particularly close. Below 2 feet it is somewhat less so. While the roots are alive, their growing tips force a way into minute cracks in the soil granules, expand and enlarge the opening, or break the granules into still finer particles. When the roots die, as happens more or less annually with the herbaceous vegetation and at longer intervals with the shrubs and trees, they soon decay, leaving channels through which water may penetrate into the soil. The beneficial effects of roots of trees, shrubs, and grass, and of such crop plants as alfalfa and sweetclover, are much greater than certain other plants because of the extent of their root systems and the size of the channels resulting from their decay.

Plant and Animal Life

The soil is the home of much of our animal life. Many animals, including most of the rodents and insectivores, such as the kangaroo rat, woodchuck, prairie dog, and badger, dwell or burrow in the soil,

emerging for food. Others, like the mole and pocket gopher, spend most of their life in the ground. Other vertebrates, such as the reptiles and amphibians, hibernate or aestivate in the soil. Some birds, even, nest in it. About 95 percent of all insect species spend some part of their existence in the soil (fig. 4). The soil teems with animal and plant life too small to be seen without a hand lens or microscope.

In forests of the Appalachian region, up to 10,000 individual microarthropods (minute animals such as spiders, springtails, centipedes, etc.) may inhabit each square foot of forest litter. These small creatures, which feed upon the litter and other organic material, aid greatly in incorporating organic residues into the soil, and in maintaining

FIGURE 4.—The larval stage of many insects is spent in the soil. Their constant working keeps the soil loose and porous and capable of absorbing large quantities of rain. Insect life is more abundant under natural vegetative cover than in the tilled field.

porosity. In the vicinity of Washington, D. C., according to McAtee (*38*) it is estimated more than 1,216,000 insects inhabit each acre of forest soils to depths to which birds can easily scratch. Analyses of soil fauna from 180 soil wells on 40 acres in the Bisenthal Forest District in eastern Prussia (*17*) show that the denser the vegetal cover the greater the number of insects in the underlying soil. Studies in Danish oak forests (*12*) disclosed that the soil was inhabited by 2,978 insects and other microarthropods per square meter, a spruce forest by 11,938 and a beech forest by 19,425.

The larvae of the Japanese beetle burrow several inches below the surface of the ground in search of food. As many as 46 larvae per square foot have been found (*26*), Darwin (*22*) estimated that more

than 50,000 worms inhabited an acre of ground. These creatures tunnel chiefly in the upper 18 inches of the soil though they may work to a depth of 7 or 8 feet. The soil brought to the surface by earthworm workings amounts to as much as 18 tons an acre a year.

Soils, especially under forest and good grass cover, contain fungus and bacterial growths. Fungus mycelia grow downward along the cracks in the soil and thus increase the intensity of the lines of cleavage. Such growths may take place to a depth of several feet. Fungi also attack dead plant material and help to break down and incorporate it into the soil. Mycelia insulate many soil particles from each other. Mycelial growth may become so dense and tenacious as to hold quantities of soil together in clumps not easily broken apart. As the mycelia die and disintegrate pore spaces are left.

All such life, plant and animal, influences the moisture intake and moisture-holding capacity of the soil, either directly or indirectly. Although the influence of such organisms has never been determined quantitatively, and perhaps never can be, they unquestionably are highly important factors in determining infiltration rates. The larger forms provide openings through which water can readily pass; the smaller forms help maintain porosity through their constant working and mellowing of the soil. They incorporate organic material into the soil, increasing the humic content and absorptive capacity.

Any modification of the plant cover and surface soil, by cultivation, burning, or overgrazing, induces conditions unfavorable to the optimum development of these soil fauna and flora, which affect the ability of the soil to take up water.

While slope is a factor in determining immediate absorption-run-off relationships at the surface, sustained favorable relationships are dependent, among other things, on soil depth and the character of underlying strata. Naturally if the soil is shallow and is underlain by a heavy impervious subsoil or by unfractured rock, rapid infiltration cannot continue. Fortunately soils with heavy indurated layers usually develop only where the topography is comparatively level. Soils occurring on sloping topography usually are characterized by more friable subsoils. Where the soil is underlain by impervious layers of subsoil or rock, water will be lost as surficial run-off, or will penetrate into the soil for a short distance only to reappear at a lower level as seepage. During flood-producing rains of short duration, this shallow seepage is often sufficiently delayed so as not to contribute to flood crests. During heavy, prolonged rains such seepage may contribute to flood crests.

Slope and Soil Influences

Slope and soil profile characteristics have a very marked influence on the infiltration and water-holding capacity of a soil and on run-off.

As slope increases, factors making for greater infiltration tend to be less effective, and increased storm flow results. Investigations to date, however, indicate that slope is of less importance as a factor affecting storm flow than degree of cover, intensity of precipitation, or inherent soil characteristics. The studies show that when the cover and other impediments to run-off are lessened, increased slope is more likely to result in proportionately greater storm flow.

The exposure of the slope, whether to the north or south, or to east or west, also influences the operation of the water cycle and absorption-run-off relationships.

While slope is a factor in determining immediate absorption-run-off relationships at the surface, sustained favorable relationships are dependent, among other things, on soil depth and the character of underlying strata. Naturally if the soil is shallow and is underlain by a heavy impervious subsoil or by unfractured rock, rapid infiltration cannot continue. Fortunately soils with heavy indurated layers usually develop only where the topography is comparatively level. Soils occurring on sloping topography usually are characterized by more friable subsoils. Where the soil is underlain by impervious layers of subsoil or rock, water will be lost as surficial run-off, or will penetrate into the soil for a short distance only to reappear at a lower level as seepage. During flood-producing rains of short duration, this shallow seepage is often sufficiently delayed so as not to contribute to flood crests. During heavy, prolonged rains such seepage may contribute to flood crests.

Infiltration After Saturation

During periods of prolonged rainfall upper layers of soil eventually become saturated, and then according to popular belief, the soil is unable to absorb more water, and all subsequent rainfall must run directly into streams. The extent to which saturation occurs depends upon the depth and character of the soil, character and condition of the plant cover, and character of the substrata. When the soil is deep and is covered with vegetation or a mat of litter, infiltration to lower levels continues after the surface soil becomes saturated, until contact is made between soil water and ground water. Water thus added to the ground supply during or immediately following a rain will rarely reappear in rivers in time to add to the crest of floods directly resulting from the rain.

In general, extremely dry soils are less capable of absorbing water than moist soils, and where soils are unable to absorb rainfall in appreciable quantities the phenomenon is generally due to the disturbance of the normal infiltration processes of the surface layer. During intense rains large amounts of surface run-off frequently originate from sloping cultivated fields in which dry soil is found 2 or 3 inches below the surface.

Studies made by the Central States Forest Experiment Station in Ohio shortly after the storms which caused the 1937 flood, showed that, while the surface soils in cultivated fields were moist, in many instances the soil at a depth of 2 or 3 feet was much drier. Forest soils, however, were invariably saturated. Pits were dug in making the observations and in several instances, under forest cover, water actually ran into the pits as soon as a depth of about 10 inches was reached.

INFLUENCES OF VEGETATION ON WATER BEHAVIOR

In the discussion of the hydrologic cycle, attention is called to how evaporation and transpiration give rise to water vapor, and how, through a process of condensation, this water returns to the land

surfaces in the form of precipitation. The rate, quantity, and occurrence of rain are beyond man's control. However, a degree of control can be exercised over its subsequent behavior after the rain reaches the land surface. By and large, its usefulness to mankind is determined by its destiny after it comes in contact with the land. If allowed to run off over the surface it may cause erosion. If it is absorbed by the soil, its run-off is retarded, it becomes available for the growth of plants useful to man, replenishes ground water supplies. In time a significant portion may reappear in streams, augmenting the low-water flow to the benefit of industries and municipalities that utilize the stream flow.

The principal factors influencing the normal division of rainfall into useful subsurface waters and less useful or destructive surface or floodwaters are the character of the precipitation, the characteristics of the soil, nature of the geologic formations, topography of the land surface, and the vegetal cover on that surface. The vegetal cover is the only one of these factors human power can control directly. Vegetation is man's strongest ally in bringing about maximum utilization instead of dissipation of precipitation. Hence the necessity for understanding how vegetal cover functions in the regimen of water. Vegetal litter must be included with living vegetation. Their functions cannot be wholly separated.

Influences on Infiltration

It is often assumed that increased infiltration resulting from a cover of vegetation or forest litter is due entirely to the actual absorption or "blotter" effect of this covering layer of organic material. Important as this spongelike action is, it is by no means most important. Lowdermilk (*36*) explains the primary functions of a vegetal cover in absorption as follows:

> When a drop of rain strikes the ground covered with a dense covering of vegetation, it breaks into a spray of clear water which finds its way into the numberless interstices and channels of the soil; but when it strikes bare soil formerly developed under a mantle of vegetation, the force of the drop causes it to take up fine particles into suspension; it becomes a drop of muddy water. As it sinks into the soil the fine particles filter out at the surface to form a thick film which chokes up the surface pores of the soil. Then only a part of the drop filters into the soil, another part is left unabsorbed and flows over the surface; the accumulation of infinite unabsorbed drops on sloping land gives rise to superficial storm flows.

How promptly and completely muddy water will plug these pores and slow the rate of percolation has been demonstrated by Lowdermilk. After establishing, over a period consisting of parts of 7 days, the rate at which clear water percolated through columns of soil, sediment of less than 2 percent by weight was introduced into the water; within 6 hours the rate of percolation fell to 10 percent of what it had been. The effect was lasting, as a return to the use of clear water did not restore the original rate.

In infiltration tests by the California Forest Experiment Station of smelter-denuded and forest-covered soils at Kennett, Calif., the average infiltration rate for denuded soils lacking litter cover was 23.5 cc. per minute, with a range of 8.8 to 41.2 cc. (fig. 5). For forest soils the infiltration rate ranged from 90.4 to 321.0 cc. per minute, averaging 263.7. Thus, the forested soil absorbed from 2.2 to 32.8

times, or on an average of 13.2 times, as much water as denuded litter-free soil.

Results from plot studies by P. B. Rowe over a 2-year period (1934–36) in the pine region of the Sierras are given in table 6.

TABLE 6.—*Surface run-off, seepage, and evaporation from litter-covered and bare-soil surfaces, North Fork, Calif., 1934–36*

Measurements	2-inch ponderosa litter cover	Bare soil
Rain ... inches	96.67	96.67
Run-off as proportion of rain ... percent	11.6	34.2
Seepage as proportion of rain ... do	62.8	30.4
Evaporation as proportion of rain ... do	25.4	35.4

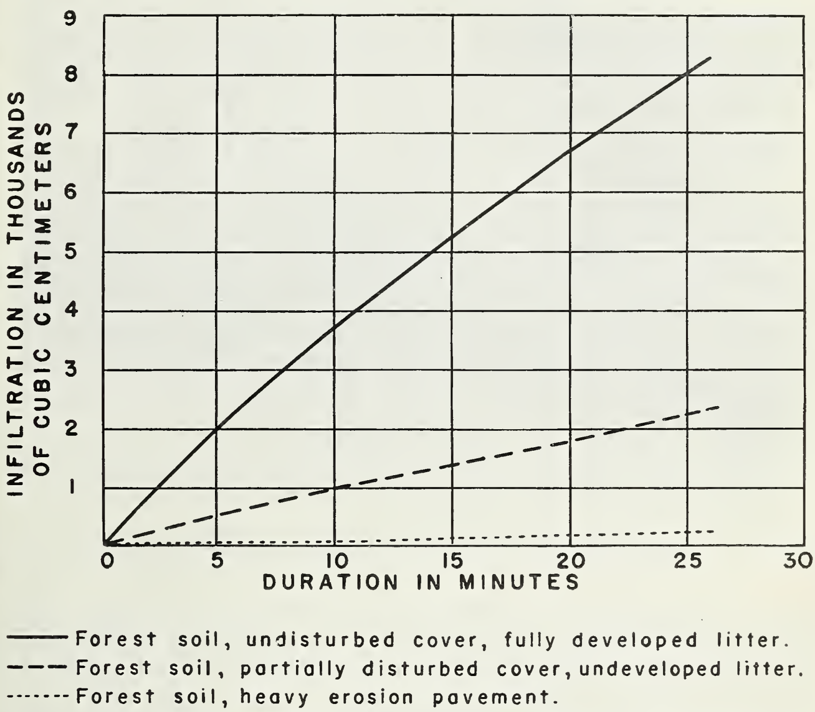

FIGURE 5.—Typical infiltration runs showing the influence of vegetation in maintaining permeability.

The benficial effect of litter cover in conserving rainfall is clearly shown in this table. The litter-covered soil permitted 22.6 percent less run-off than the bare soil and 10 percent less evaporation, a saving of 31.32 inches of water. This saving of rainfall is accounted for by seepage alone, for only 30.4 percent of the rainfall seeped into the bare soil plot while 62.8 percent seeped into the litter-covered plot.

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Interception of Precipitation

Anyone who has taken refuge under a tree during a summer shower knows that the crowns of the trees intercept and hold a portion of the rain. Later this evaporates. But if the rain is prolonged until the leaves and branches are thoroughly wet, the remainder of the fall drips from the trees. It is only delayed in reaching the ground.

Rainfall records have been taken at paired stations inside and outside of timber stands to discover the amount caught (fig. 6). A good pulpwood stand of spruce, fir, and some paper birch in Maine intercepted 26 percent of the rainfall; another stand of pure spruce-fir intercepted 37 percent. A dense saw-timber stand of white pine and hemlock in Massachusetts intercepted 24 percent; and a heavy

Figure 6.—Many measurements have been made of the effect of forest cover on interception of precipitation by the crowns of trees.

virgin white pine and hemlock stand in Idaho, 21 percent. Open second-growth forests of oak and hard pine in southern New Jersey intercepted 13 percent of one summer's rainfall; and jack pine and hardwood-hemlock stands in Wisconsin, 22 and 19 percent, respectively, of the spring and fall precipitation. The Wisconsin hardwoods when in leaf intercepted 25 percent of the precipitation, as against 16 percent after the leaves fell.

Studies in North Carolina by the Appalachian Forest Experiment Station of interception of precipitation by tree canopies have shown that in the case of significant rains of 0.20 inch or more, the amount of precipitation intercepted by the crown canopies may be from 1 to as much as 33 percent of the total. The controlling factors are composition, age, and condition of the stand, and the season of the year.

Interception of snow by the crowns of ponderosa pines at about 4,500-feet elevation in Idaho was studied by the Intermountain

Forest Experiment Station during 1931–32. In a good stand of virgin timber with an understory of young trees, it was found that up to the time of maximum storage 27 percent of the winter's snow had been intercepted; in similar mature timber without an understory it was 22 percent; and in a somewhat open stand of ponderosa and lodgepole pine, 20 to 30 feet tall, 8 percent. Studies elsewhere in the West by Church (*19*), Jaenicke and Foerster (*34*), and Griffin (*30*), however, indicate that snow interception is considerably less in evergreen forest types.

While few data are available as to the interception of precipitation by forms of vegetation other than trees, general observations indicate that such interception has an appreciable effect on the water cycle. Anyone who has walked through a field of grass, hay, or corn after a rain realizes that a considerable portion of the pecipitation clings to the leaves and must later either pass down the stalks of the plants to the soil or be lost through evaporation. Table 7 shows measurements obtained at the Soil Conservation Experiment Station at Clarinda, Iowa, by imbedding a series of containers in the soil under each of several types of cover.

TABLE 7.—*Canopy interception of rainfall,[1] Clarinda, Iowa, 1935*

Date	Rainfall measured under—				Rainfall interception by—		
	Fallow	Corn	Alfalfa [2]	Clover [2]	Corn	Alfalfa	Clover
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
Aug. 10	0.245	0.184	0.190	0.183	0.061	0.055	0.062
Aug. 17	.973	.629	.670	.775	.344	.303	.198
Aug. 19	.064	.047	.060	.062	.017	.004	.002
Aug. 20	.252	.201	.220	.230	.051	.032	.022
Aug. 22	.544	.488	.518	.485	.056	.026	.059
Aug. 29	.040	.032	.038	.040	.008	.002	.000
Sept. 2	2.294	1.999	1.905	1.967	.295	.389	.327
Sept. 9	.753	.542	.602	.603	.211	.151	.150
Sept. 16	.451	.293	.370	.353	.158	.081	.098
Sept. 25	.069	.042	.040	.053	.027	.029	.016
Sept. 26	2.109	1.614	1.527	1.620	.495	.582	.489
Oct. 7	.122	.106	.097	.073	.016	.025	.049
Total for period	7.916	6.177	6.237	6.444	1.739	1.679	1.472

[1] Rainfall caught near ground level. Each figure represents the average of 12 replications each of fallow and corn and 6 replications each of alfalfa and clover.
[2] Alfalfa and clover were harvested July 15.

Although the amount of rain intercepted by vegetation may reach a considerable percentage of the total annual precipitation, the amount intercepted in a given rain necessarily is limited. A relatively large part of light rainstorms is prevented from reaching the soil, whereas in heavy rains the proportion is much smaller. Consequently interception is of little consequence in reducing the amount of run-off in time of flood-producing storms but may be a considerable factor in reducing the moisture supply for plant growth.

Reduction of Evaporation From the Soil

Vegetation, particularly forest cover, greatly reduces the rate of evaporation from the soil. In Arizona, summer evaporation a few feet above the ground within a forest of ponderosa pine may be only 70 percent of the evaporation in the open (*46*). Evaporation beneath

a dense virgin forest of western white pine and hemlock in Idaho during July and August was found to be only 22 percent of that in an area clear-cut and burned, and in a similar stand from which about 65 percent of the cover had been removed it was only 47 percent. Bode (*11*) states that in a heavy oak stand in Iowa summer evaporation was 47 percent and in a reproducing cut-over area 74 percent of that in the open. Evaporation during one spring in a rather open, short-bodied stand of mature pine and oak in southern New Jersey was found to be only 65 percent of that in the open.

The effect these very substantial reductions in evaporation rate within the forest have upon soil moisture has never been fully determined. There are almost no American data on seasonal evaporation from a bare soil. European evidence, as quoted by Zon (*58*), shows wide variations, but indicates that evaporation from bare soil in the open, under average conditions, amounts to about 50 percent of precipitation; and that a forest, even without leaf litter, may reduce this to 15 to 25 percent.

Water Consumed by Vegetation

The water which plants withdraw from the soil in maintaining growth and life is transpired, or given out into the air. The water requirement varies considerably with different plants. The average water requirement (units of water required to produce one unit of dry matter) of several crops at Akron, Colo., was determined as follows (*14*):

Crop	*Water-requirement units*	*Crop*	*Water-requirement units*
Wheat	513	Clover	797
Barley	534	Peas	788
Maize	368	Potatoes	636

According to Miller (*42*) the total amount of water transpired from plants during a growing season depends primarily upon prevailing climatic conditions. Data obtained at Manhattan, Kans., and presented in table 8 will serve as an example of the relatively large amounts of water transpired by plants.

Table 8.—*Water loss by plants of various kinds, Manhattan, Kans., 1924–25*

Plant	Length of season	Total water lost during the season per plant
		Gallons
Cowpea	May 19 to Sept. 2, 1924	13
Potato, Irish cobbler, 1 hill, 2 to 3 plants	Apr. 18 to July 30, 1924	25
Tomato, Louisiana Pink, pruned to 1 stem	May 19 to Sept. 2, 1924	34
Corn, Kansas sunflower	May 5 to Sept. 8, 1924	54
Winter wheat, Kanred, 1 plant, 15 stalks	Oct. 15, 1924, to June 28, 1925	25
Sunflower, Russian	May 26 to Aug. 23, 1925	123
Sunflower, wild	May 24 to Aug. 23, 1925	130
Giant ragwood (*Ambrosia trifida*)	May 24 to Aug. 23, 1925	140

Using the data in this table as a basis, Miller estimates that an acre of corn would transpire 324,000 gallons, or 1,296 tons, of water during

the growing season. This is equivalent to approximately 11 acre-inches of rainfall.

Although in more humid portions of the country, the loss of water might not be so great, the importance of soil-moisture storage for crop production, as well as for run-off control, can readily be seen from these figures. Field crops in any part of this country rarely have access throughout the growing season to a supply of soil moisture sufficient for optimum growth. Much of this lack of soil moisture during the growing season can be directly attributed to high run-off, which, throgh the application of water-conservation practices on the land, could be materially alleviated.

It is very difficult to measure accurately the transpiration from a single tree larger than a seedling, and infinitely more so to measure the transpiration from a forest. In one instance in southern California, observations of stream flow have been employed to determine the amount of water evaporated from the soil or consumed by canyon-bottom vegetation—willows, tules, and kindred moist-land growths (*10*). The evapo-transpiration losses from Temescal Canyon during only 30 spring days was found to equal 12.9 inches of rainfall. It was estimated from stream-flow measurements in Coldwater Canyon that the transpiration draft by riparian vegetation consisting of alders, sycamores, bay, oak, and herbaceous growth during the 6-month summer season of 1931 totaled 45 inches an acre. These transpiration losses are doubtless greater than for the average forest type in the United States, since the riparian vegetation had access to a constantly saturated soil. Such condtions fully warrant the expedient, already adopted by such cities as San Bernardino, where water is scarce, of piping water out of the stream channel before it can be consumed by the canyon-bottom forest.

Data on transpiration rates for other American forest types are lacking and these rates may only be inferred from general knowledge. Many of the statements widely quoted as to the amount of water used by trees and other natural vegetation have been based on European data. These data, taken on small potted plants or on twigs and small branches cut from trees, cannot be applied universally to large trees grown under forest conditions, and cannot safely be applied to American species or to American conditions (*47*).

Consumptive use of water by vegetation is also related to soil fertility and erosion. Plants growing on fertile soil can make more efficient use of water than plants growing on infertile soils. This has been demonstrated with corn as follows (*35*):

Soil	*Water-requirement units*
Infertile	550
Intermediate	479
Fertile	392

In other words, on a cultivated, eroded, infertile soil, plants require a larger number of units of water to produce a unit of dry matter. Associated with this problem, however, is the fact that such soils will usually, because of a lower absorptive capacity, actually have less water available for plant use. This intensifiies the hazards of crop production on poor, submarginal lands.

Absorption by Plant Litter

A minor effect of litter upon run-off is its capacity to absorb moisture. A number of investigations have determined the water-holding capacity of litter from typical forests in various parts of the country.

In the Northeast the water-holding capacity of the litter ranges from 300 to 900 percent of its dry weight, the highest values being obtained in the spruce and in the northern hardwood forest. Freshly fallen pine litter in the Lake States absorbs water up to 156 percent of its dry weight. In the Central States region the absorptive capacity of scanty hardwood litter averages about 360 percent. In the southern hardwood forest it ranges up to 400 percent, and in the southern pines from 150 to 350 percent. The lowest values are for freshly dropped litter. In the Appalachian Mountains the water-absorptive capacity of the litter ranges from 300 to 535 percent.

Data obtained for the Appalachian Mountains illustrate the influence exerted by litter upon the water conditions of a large region. The values here given doubtless would be too low if applied to the whole hardwood-forest region, but they are indicative. In the study it was determined that the absorptive effect of hardwood litter is greatest on the middle and upper north slopes and lowest on the upper south slopes in the Appalachian region.

Investigations in Ohio by the Central States Forest Experiment Station indicate that comparatively young plantations considerably influence run-off and erosion. Forest plantations ranging in age from 12 to 20 years had developed a uniform litter cover which was rapidly increasing in depth and in value. The absorptive capacity of the forest floor was determined as ranging between 100 and 250 percent of the dry weight of the material, indicating the possibility of an absorption of more than 0.20 inch of rainfall. The Red Plains Soil Conservation Experiment Station near Guthrie, Okla., found the litter on a post oak area to have a water-absorption capacity of 16.7 tons per acre.

In peat deposits, which are characteristic particularly of the spruce forests of the Lake States and the higher portions of the Appalachian Mountains in the Ohio River drainage, the amount of water absorbed may easily be several inches, this amount being dependent upon the depth of the deposit. Moss peat (*21*) has an absorptive capacity of approximately 5,200 tons of water per acre-foot of dry matter; reed and sedge peat have an absorptive capacity of approximately 4,100 and 3,500 tons respectively. These quantities of water amount to 167,000 cubic feet per acre for moss peat and 131,000 and 112,000 for reed and sedge peat, respectively.

Retardation of Run-off

The mechanical retardation effect on run-off brought about by the presence of vegetation and litter on the ground surface has not been measured accurately. It is evident, however, that it is of considerable importance; by holding the water on the surface for a longer period, the soil is given greater opportunity to absorb it. Over a sloping surface covered with grass or litter during a heavy rain there is a slowly moving film of water. The head of water is greater than that found on a similar slope of bare ground. To this extent

additional infiltration is forced. Musgrave (*45*) shows the importance of this retardation effect with data obtained on a 9-percent slope of Marshall silt loam in southwestern Iowa (table 9). The period covered was July 1, 1934, to December 31, 1935.

TABLE 9.—*Run-off in relation to slope length on a 9-percent slope of Marshall silt loam in Iowa under corn and bluegrass*

Crop	Slope length	Run-off surface	Times run-off occurred
	Feet	*Inches*	*Number*
Corn	3	9.81	37
Bluegrass	3	6.59	33
Corn	72.6	5.07	22
Bluegrass	72.6	.50	4

Musgrave adds in explanation of these data:

A logical conclusion, therefore, is that a very important effect of close vegetation is to reduce the velocity of surface movement and thus allow more time for infiltration to take place.

RETARDATION OF SNOW-MELT

One of the important effects of forest cover in regions of heavy snow is to retard melting in the spring. This lessens destructive run-off and promotes infiltration of snow water into the ground. Melting of snow under forest cover takes place at a slower rate than on interspersed open land. Moreover, since the ground in the forest is less likely to be frozen and is usually more absorptive, the prolongation of the melting period results in a higher percentage of snow water being absorbed. On the other hand, snow that has not melted may be carried off by a heavy early spring rain and thereby contribute to flood flows.

The retardation of snow melting is due in part to shading of the ground, and in part also to reduction in wind movement. In Idaho snow in a mature forest with an understory of small reproduction disappeared from 3 to 10 days later than snow in the open, at least 10 days later in Nevada; several weeks later in Arizona, where the snow occurred mostly in drifts in the timber; and from 1 to 5 weeks later in Washington (*44*). Ashe reported that 20 inches of snow which fell at an elevation of 600 feet in Maryland during March 1906, was 9 days longer melting beneath a cover of Virginia pine than in the open. Wind movement during the period of the Idaho study was nine times greater in the open than in the mature forest. Wind movement in the open ponderosa pine forest in Arizona was less than half that in the open.

The city watershed of Little Falls, N. Y., has been partly reforested. Ray P. Bower of the New York State College of Forestry and R. D. Austin, city engineer of Little Falls, observed that over a period of 10 years the snow cover in these plantations did not entirely disappear for from 10 days to 2 weeks after the disappearance of snow in open fields.

In New England in March 1936 heavy rain fell on deep snow. The rain and warm winds hastened the melting of the snow. There is

difference of opinion as to the effect of the snow in forested areas on the flood that occurred. One opinion is that, the ground being frozen, most of the snow-melt ran off. Observers on the ground, however, said that soil in the open fields was frozen but that in the woods the soil was not frozen, and, being free of frost, it was able to absorb much of the water.

From their studies of thermal relationships, Baldwin and Brooks concluded:

> If the State of New Hampshire had been covered with a dense stand of spruce, hemlock, fir, and pine, the flood of March 1936 would have been merely the flood of the decade instead of the great flood of the century. The flood would have been greatly reduced because some of the deep snow cover would have remained unmelted and would have held back the melt-water and rain.

Grass and field crops collect and hold snow. This is important in areas subject to relatively high winds, such as the Prairie and Great Plains regions.

Prolongation of melting is less marked where the vegetation is low. Results at the Upper Mississippi Valley Soil Conservation Experiment Station near La Crosse, Wis., indicate that grass, while not as effective in the winter as in other seasons of the year, does influence winter run-off importantly. The data in table 10, covering a 3-year period, show this.

TABLE 10.—*Effect of season on run-off on a 16-percent slope near La Crosse, Wis.*

Season	Run-off on fallow	Run-off with blue-grass cover
	Inches	*Inches*
Winter (Nov. 16 to Apr. 15)	1.70	1.15
Spring (Apr. 16 to May 30)	.59	.05
Summer (June 1 to Aug. 31)	3.48	.04
Fall (Sept. 1 to Nov. 15)	1.66	0

PROTECTION FROM FREEZING

As a factor contributing to greater direct run-off of melted snow or early spring or winter rains, the frozen condition of the soil is frequently emphasized. It is assumed, perhaps, that soils freeze sufficiently to prevent absorption regardless of cover conditions whenever the air temperature remains below freezing for a considerable period. Available information, though meager, indicates that frozen soils do not occur under deep snow cover or good plant cover as commonly as is generally supposed. That absorption may be greatly reduced when the soil is frozen seems fairly obvious, but the extent to which the soil actually is frozen is a matter which merits careful consideration. Snow cover alone has a material effect on the depth to which the soil may be frozen. The depth and distribution of snow, in turn, are influenced by the character of the plant cover.

Bouyoucos, as shown in table 11, found that the soil temperature at 3 inches below the surface did not fall much below freezing under a cover of snow alone, that soil did not freeze under a cover of snow and vegetation, whereas subfreezing temperatures were almost continuous in bare soil. He concludes from 4 years' study that in excep-

tionally cold weather soil protected by vegetation and a layer of snow may have 25° F. higher temperature than a bare soil at a 3-inch depth, and that the soil temperature fluctuates less under snow than where the soil is bare.

TABLE 11.—*Effect of snow cover on soil temperature at 3-inch depth, January 1915*

Temperature determined	Temperature of the air	Soil temperature at depth of 3 inches		
		Bare	Snow bare	Snow uncompacted, vegetation
	°F.	*°F.*	*°F.*	*°F.*
Maximum	+41	32.3	32.3	35.7
Minimum	−13	7.5	27.0	32.0
Average maximum	+27.96	28.79	31.51	34.82
Average minimum	+13.80	24.95	31.11	34.55

Research of Diebold and Spaeth, in the Arnot Forest, near Ithaca, N. Y., illustrates the insulating effect of vegetation. The soil temperature in a field during two representative 1-week periods in February and March 1936, remained well below the freezing point. The soil temperature under forest cover, where the depth of snow was 30 inches compared to 8 inches in the open, remained at approximately 32° F., the soil was not frozen. A series of determinations of frost penetration made near Mt. Vernon in Knox County, Ohio, February 13, 1936, were as follows:

Cover conditions	*Average depth to which the soil was frozen*
Woods, well managed; protected from grazing for the preceding 10 years	0 to 4.
Woods, protected from grazing for the preceding 15 years, but heavily thinned during the winter of 1935–36.	3 to 8.
Woods, heavily pastured	6½ to 10.
Meadow, fair stand and fair growth	16.
Pasture, poor stand and poor growth	17.
Corn land, fall seeded to wheat	18.

Several hundred determinations of snow depth and frost penetration were made during the winter of 1935–36 on the 150,000-acre watershed of Big Creek in north-central Missouri. The amount of snow held by vegetation and the effect of the snow and vegetal litter in minimizing frost penetration are shown in table 12.

TABLE 12.—*Determinations of snow depth and frost penetration in Big Creek Watershed, Mo., under different cover conditions*

Cover condition	Average snow depth	Average frost penetration	Estimated absorption during thaw
	Inches	*Inches*	*Percent*
Barren	0 to 4	25	0 to 50
Vegetative cover (not over 5 inches tall)	4 to 10	12	50 to 90
Vegetative cover (over 5 inches tall)	10 to 24	5	90 to 100

In Utah, where snow accumulates to a depth of several feet, the soil does not remain frozen throughout the winter. Although the soil often froze to a depth of several inches in early winter before

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a deep snow blanket had accumulated, actual temperature measurements made at monthly intervals showed that the soil thawed later in the winter under the snow cover, evidently because of heat conducted from lower levels. The temperature just below the surface of the soil then remained at approximately 31.50° F.

CONSEQUENCES OF CHANGE IN VEGETAL COVER

Preceding sections have described the hydrologic cycle, the normal behavior of water on the land, how plant and certain animal life affects this behavior, and certain other basic relationships. This section deals with the extent of modification of plant cover and surface soil by clearing and cultivation, fire logging, overgrazing, and improper pasture management; and presents quantitative measurements for specific areas, showing the consequences of cover change in terms of run-off and erosion.

Extent of Modification of Cover

Of the total 1,903 million acres in the United States, some 413 million now are being tilled for agriculture. Approximately 615 million acres, compared with the original area of 820 million acres, are now classed as commercial forest land. Pasture and range, exclusive of grazed forests and woodland areas, total about 696 million acres. Farmsteads, roads, urban developments, wastes, and similar areas account for the remaining 179 million acres of land.

Present cover classifications, however, do not afford a complete picture. Large areas, especially in the East and South, were cleared for agriculture and subsequently abandoned, largely because of erosion, and now are more or less covered with brush or scattered stands of trees. In the West several million acres of land were dry-farmed for a while and then abandoned. Much of this land has not, as yet, been reclothed.

As the country was settled, hundreds of millions of acres of forests and grassland necessarily gave way to agriculture. During the period of extensive agricultural development, settlers paid little regard to the inherent productivity of the soil or its erodibility. Immediate profit was the immediate interest of many of the settlers as well as most of the land promoters. Little thought was given to conserving a resource as seemingly inexhaustible as the soil, and few farmers gave consideration to conservation practices. Consequently, millions of acres that should have remained permanently in timber or grass were put to the plow. Other millions of acres suitable for cultivation were farmed exploitively rather than conservatively.

Existing forest lands, from the standpoint of plant cover, afford conditions vastly different from what might be readily maintained. Eighty-three million acres of cut-over and burned-over commercial forest land is classed as either poor or not restocking. Approximately 850 thousand acres are cut-over destructively or devastated each year. Fire annually sweeps over some 40 million acres of forest lands in the United States, removing a part or all of the cover and its vegetal litter. Much of this area reburns annually or periodically and other areas reburn intermittently, so that normal

conditions are disturbed every few years on a large part of the forest areas.

In a recent extensive survey of the 728 million acres of range land in the western half of the United States, of which 216 million acres are classed as forest land, 34 percent was found to be 26 to 50 percent depleted; 37 percent, 51 to 75 percent depleted; and 16 percent, 76 to 100 percent depleted (*55*). These figures of depletion are expressed in terms of grazing capacity and in the main represent displacement of the better forage plants. The loss of forage cover has been in part compensated by an increase of non-forage plants, but on the whole there has been a great reduction in total plant cover. More or less serious accelerated erosion is affecting 80 percent of the entire range area. In eastern United States many pastures also are suffering severely from mismanagement, which has resulted in reduction in fertility of pasture soils, diminution of plant cover, and compacting of the soil by trampling.

The consequences of the unwise land use of the past are indicated by a survey of erosion conditions made by the Soil Conservation Service in 1935. This survey shows that approximately 50 million acres of land formerly under cultivation in the United States has been essentially destroyed for agricultural purposes by erosion. In addition to this, 50 million acres has lost practically all of its productive topsoil and is rapidly nearing total destruction.

> Approximately 100 million acres still largely in cultivation has lost all or the greater part of the topsoil. In short, half of the better cropland of the Nation has been affected by erosion in degrees varying from the state of incipiency to complete destruction. Tens of thousands of farmers have become subsoil farmers, which means something very close to bankrupt farming on bankrupt land (*9*).

Along with the impoverishment of soils through erosion there has occurred the destruction of large areas of alluvial valley lands through the deposition of gravel, sand, and unproductive subsoil material washed from the uplands. Deposition of debris in stream channels and storage reservoirs has increased flood damage, necessitated large expenditures for dredging, and has virtually destroyed the utility of a large number of storage reservoirs.

Run-off Measurements

Most of the results of run-off studies here presented are taken from findings of the field experiment stations of the Department of Agriculture. The Soil Conservation Service, in cooperation with the State agricultural colleges, has 12 soil erosion experiment stations. The first of these was established in 1929. They deal primarily with agricultural lands. The Forest Service through its 12 regional forest and range experiment stations has conducted studies of soil and water relations on forest and range lands at more than 20 localities in the United States. The first of these studies was begun in 1909. The investigations of these agencies have been supplemented by observations and demonstrations in the national forests and in soil conservation demonstration areas. Also, the State agricultural experiment stations in Missouri and Texas have investigated erosion and run-off for several years. The Bureau of Chemistry and Agricultural Engineering, the Bureau of Plant Industry,

the Weather Bureau, and other agencies of the Department of Agriculture are carrying on supplemental work.

The Federal experiment stations at present have under way upwards of 500 individual field and laboratory studies involving the effectiveness of vegetal cover and land use in reducing run-off and erosion. Many of these studies involve precise measurements of rate and quantity of precipitation and the resulting run-off and erosion on carefully controlled areas varying from small plots to watersheds up to 30,000 acres. Data are being accumulated for every rain or snowfall on each of these plots and watersheds. The number of rains that produce storm-flow, of course, varies from locality to locality, and from year to year. Assuming an average of approximately 18 rains a year at each experimental center, approximately 9,000 measurements are made each year. Many of the studies have not been under way long enough to warrant drawing conclusions. The results of a number of the older tests are presented here without much discussion. In the main they are self-explanatory.

Clearing and Cultivation

Land must be cleared and cultivated. Food and fiber requirements necessitate it, even where the cultivation process may harbor the seeds of land destruction. Permanent agriculture in tilled crops has been achieved only on a comparatively small area of the earth's surface. The agricultural history of many of the older nations indicates that populations living on sloping lands are finally driven to level lands or to bench terracing of slopes, because of accelerated erosion and run-off. Probably three-fourths of our 2 billion earth-bound inhabitants live on plains and low uplands where main drainages are visited by floods, the source and causes of which are often, if not generally, in another physiographic environment.

Although the hazards to the land of cultivation have long been recognized, until recent times they had not been subjected to measurement. The measurements have disclosed the nature of the threat to a permanent agriculture. It may be worth while to review some of the results.

The effect of clearing and cultivation without water-and-soil-conservation practices is strikingly illustrated by measurements made at the erosion experiment station at Ithaca (fig. 7) during the period March 1 to March 19, 1936. This period immediately preceded the 1936 flood on the watershed of one of the upper tributaries of the Susquehanna River (*9*). Water losses from a potato field on land having a slope of 14 percent amounted to 88 percent of the total precipitation, and soil was lost at the rate of 0.53 ton per acre. Of 9.47 inches of rain and snow, 8.38 inches was lost as run-off during this critical period. The corresponding loss of water from a neighboring forested area, with a slope of 27 percent, was approximately 0.5 percent of the total precipitation. It is significant to note that the ground beneath the cover of forest litter was not frozen, whereas the soil in the potato field was. Of equal interest also, is the fact that from neighboring grassland, with a slope of 20 percent, the ground of which was not frozen, the run-off was less than 0.2 percent of the total precipitation, and there was no soil loss. Another grass plot, with a 14-percent slope, where the ground was frozen owing to lack

of sufficient protective cover, lost 88 percent of the total precipitation, but even here there was no measurable soil erosion.

Studies on sample plots on the upland loess soil of northern Mississippi further show the tremendous capacity of certain vegetated soils to absorb large quantities of moisture. At the time of the disastrous flood of the Yazoo River in 1931–32, when 27 inches of rain fell, 62 percent ran off cultivated fields immediately and carried soil with it at the rate of 34 tons an acre. On barren abandoned fields the run-off was 54 percent of the total rainfall. During the heaviest rains from 75 to 95 percent of the rain falling on these classes of land became surface run-off. On the other hand, of the 27 inches of rain falling on an undisturbed oak forest, less than 0.5 percent ran off the surface, taking only about 75 pounds of soil an acre. Run-off from a plot located in a scrub oak forest with a litter cover was only 2 percent of the rainfall. In short, the surface run-off from land in cultivation was 127 times greater than from forest

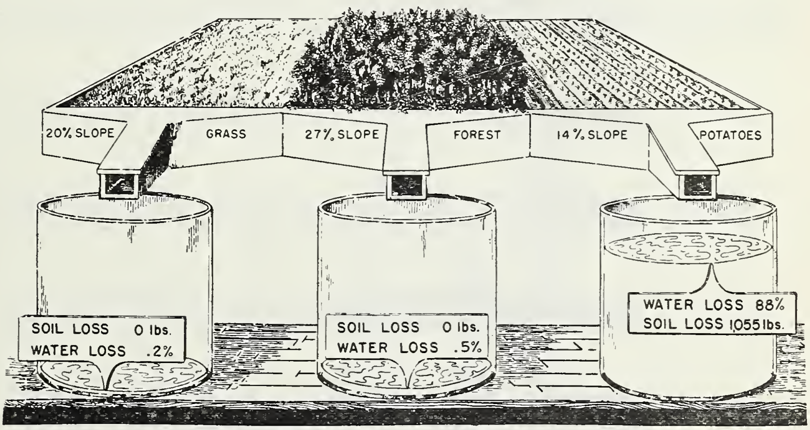

FIGURE 7.—The effect of clearing and culitvation without employing water- and soil-conservation practices is illustrated by measurements at Ithaca, N. Y., preceding the 1936 flood on a tributary of the Susquehanna River.

land, for the period of observation, and the amount of soil carried off was over 900 times greater.

During the 2-year period (October 1931 to September 1933, inclusive) that this study was carried on, the rainfall totaled 130.70 inches, or 25 percent more than normal. It occurred as 103 rains (or series of rains) of from 0.03 to 5.32 inches each. About 28 percent of the precipitation occurred as torrential rainfall, and 20 percent as rains of moderate intensity. Surface run-off from a plot in a cultivated cottonfield in which the rows paralled the slope amounted to 58 percent of the total precipitation. In individual rains surface run-off amounted to as much as 96 percent of the precipitation. Soil loss amounted to 195 tons to the acre for the 2 years. From a cultivated cotton field in which the rows paralleled the contour, run-off amounted to 47 percent of total precipitation, and soil loss totaled 69 tons to the acre. From barren plots in an old field there occurred a total run-off amounting to 48 percent of the rainfall, and erosion

totaling nearly 160 tons an acre. The run-off from unburned broomsedge plots in an old field amounted to only slightly more than 1 percent of the rainfall, that from the oak forest to less than 1 percent. During no rain did run-off from land of these 2 classes exceed 5.05 and 3.10 percent of the rainfall, respectively. Erosion from these lands was almost negligible. Comparisons of the run-off, eroded material, and absorption from the several plots in this study are shown in figure 8.

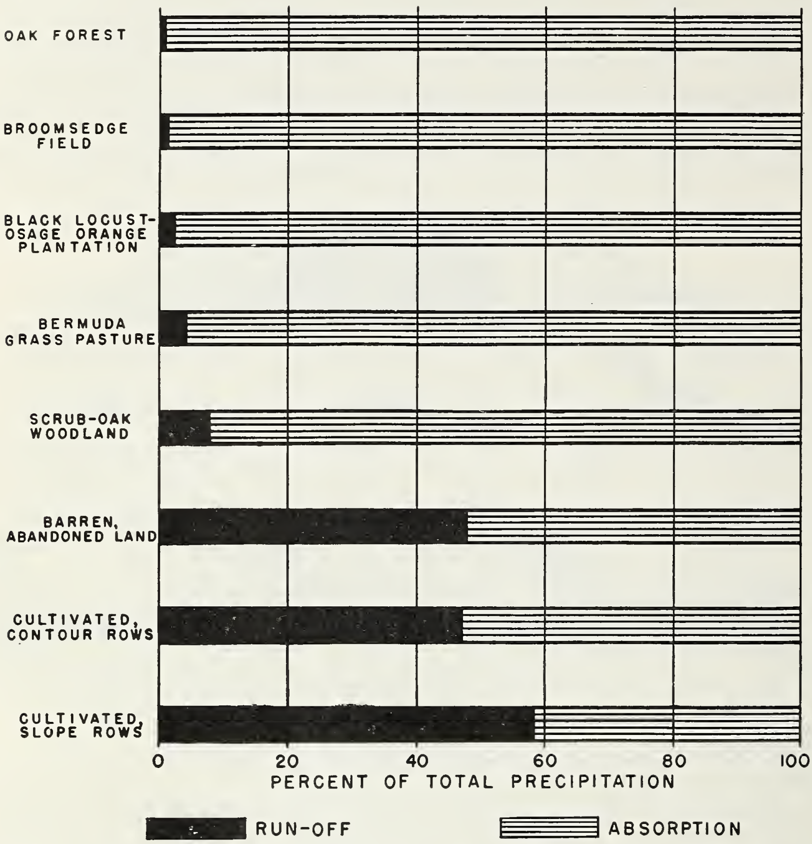

FIGURE 8.—Results of 2-year measurements of run-off and absorption under different types of land uses, at Holly Springs, Miss., October 1931 to September 1933. Rainfall 130 inches.

Figure 9 shows the relative water and soil losses under different cropland conditions for a single rain of high intensity at one of the soil conservation experiment stations. These data are indicative of run-off and erosion originating from areas covered with close-growing vegetation as compared to clean-cultivated areas at all the stations. Although the relative difference between these two treatments may vary from station to station and at a given station from time to

time, invariably, rain after rain, the effectiveness of close-growing vegetation in reducing run-off stands out strikingly. This trend is consistent.

Duley and Miller (*23*) found that whereas only 11.5 percent of 6 years' rainfall ran off a sloping surface protected by a permanent grass sod kept clipped, 49 percent ran off bare soil. Even where tilth of the bare soil was maintained by annual cultivation, nearly 30 percent of the precipitation was carried off over the surface. Measurements on the silt loam uplands in southwestern Wisconsin with slopes averaging 36 percent, show that the proportion of total summer precipitation which ran off over the surface of the ground beneath hardwood forests of varying density averaged 2.8 percent (*7*). Wild pastures of native grasses, in which the soil had never been cultivated, yielded a surface run-off about 2½ times as great. Cultivation greatly increased the percentage of surface run-off; from cultivated hayfields it averaged 17.7 percent, and from small grainfields, cornfields, seeded pastures, and fallow land it averaged over 25 percent.

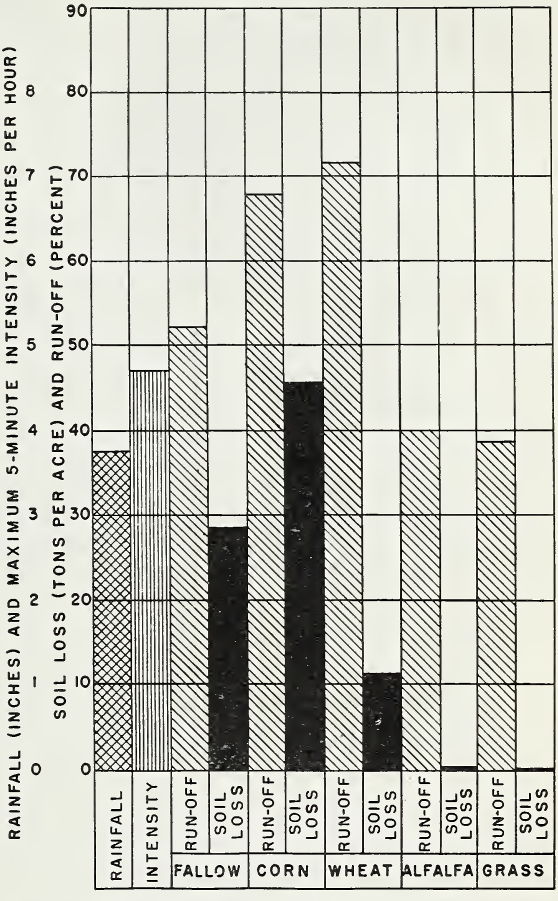

FIGURE 9.—Effect of plant cover on run-off and soil loss on an 8-percent slope during rain of high intensity, April 3, 1934, at Bethany, Mo.

Comparisons of flood flows from depleted and abandoned agricultural land with run-off from wooded areas have been obtained in the Appalachian region. Records of the continuous flow of streams from eight small watersheds in the Bent Creek Experimental Forest near Asheville, N. C., represent different types of forest and other vegetal

cover for periods of from 1 to 2½ years. They show that for the period from July 1, 1933, to October 30, 1936, the average maximum flow recorded for any forested watersheds amounted to 84 cubic feet per second per square mile, whereas a flow of 403 and 785 cubic feet per second per square mile was recorded for abandoned agricultural land and for pastured standard agricultural land, respectively. In no case did the storm run-off from forested watersheds assume critical flood conditions, whereas from the nonforested watersheds, numerous instances occurred in which the maximum flow assumed serious flood proportions.

A summary of the precipitation and storm flow resulting during the 19 maximum storms occurring in the Bent Creek area between July 1, 1933, and October 30, 1936, is summarized in table 13. The pastured abandoned agricultural land gave an average peak unit flow 18.7 times greater, and the abandoned farm land 9.2 times greater, than the average of all forested watersheds. Watershed number 4, mostly forested, had an average peak flow 1.5 times greater than the wholly forested area. Run-off coefficients vary in approximately the same manner. The effect of forest cover in reducing the peak flow is illustrated by the hydrographs of 3 of these areas for a storm in October 1934, when over 2 inches of rain fell, figure 10.

The relation of cover condition to peak flows is further demonstrated by studies in Copper Basin, Tenn., where plant cover has been completely destroyed by smelter fumes on an area formerly covered by hardwood forest. This area represents what happens when there is ultimate complete destruction of the vegetation. Peak flows from the denuded watersheds are compared with the flows from forested and partly grazed watersheds in the following tabulation:

Watershed condition	*Maximum rate of flow in cubic feet per second per square mile*
Forest	30
Do	56
Incomplete broomsedge cover	832
Do	900
Denuded	1,263
Do	1,434

Peak flow, however, is not the only run-off condition that contributes to floods in the larger streams. Much depends also upon the total discharge during a flood-storm period. In table 14 is shown the percentage of precipitation which ran off three of the watersheds in the Bent Creek area, cited above, during several of the major storms that occurred during the period studied. In one case only, during the storm of March 26, 1936, did the percentage of run-off from the forested area exceed that from either the abandoned agricultural land or the pastured abandoned agricultural land. The widest difference in percentage of run-off between forested and nonforested watersheds occurred during the summer period.

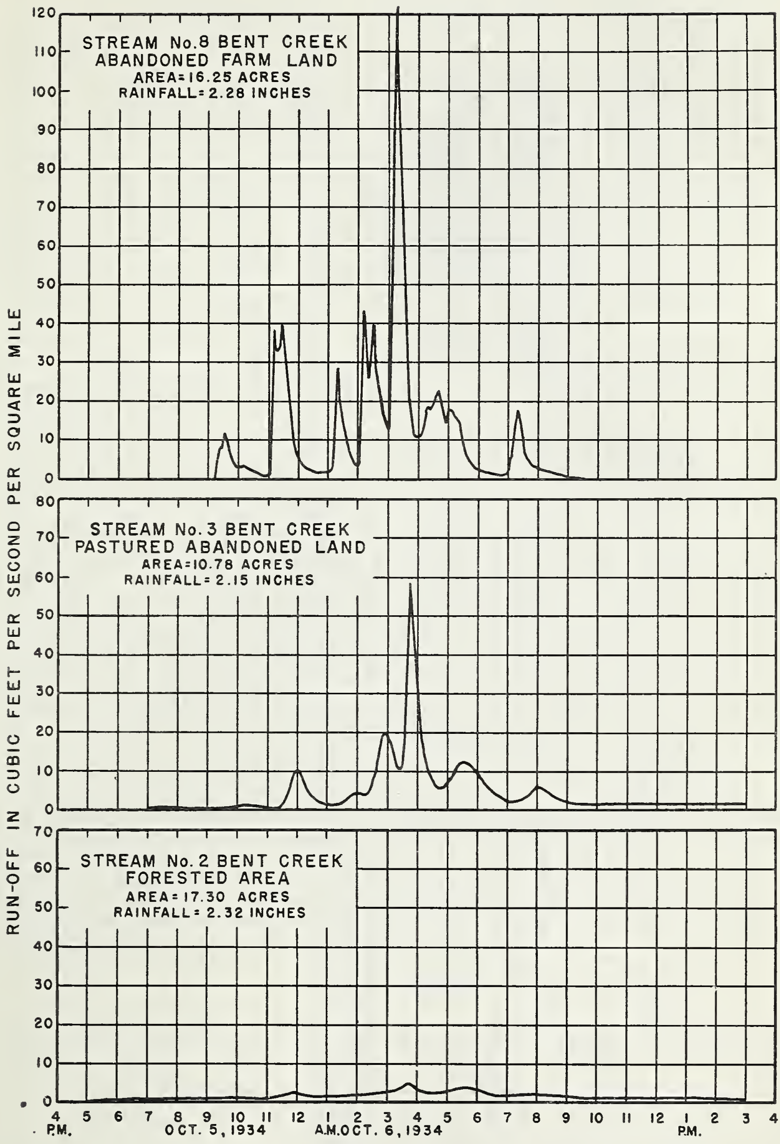

FIGURE 10.—Chart of run-off from three watersheds under three types of cover during storm of October 5 and 6, 1934, at Bent Creek Experimental Forest, N. C.

TABLE 13.—*Analysis of 19 storms, July 1, 1933 to Oct. 30, 1936, Bent Creek Experimental Forest, N. C.*

Type of land	Storm description				Intense rainfall				Run-off data					Run-off coefficient (C)[4]
	Average precipitation	Average duration		Average intensity per hour	Average duration		Rate per hour	Average maximum 20-minute period	Avenue peak flow (Q)[1]		Time of concentration			
											Average duration	Intensity per hour (I)[2]	Area (A)[3]	
	Inches	*Hours*	*Minutes*	*Inches*	*Hours*	*Minutes*	*Inches*	*Inches*	*Cubic feet per second*	*Cubic feet per second—square mile*	*Minutes*	*Inches*	*Acres*	
Forested	1.91	9	10	0.21	1	18	0.68	0.41	1.246	16.41	200	0.34	48.6	0.0753
	1.76	9	15	.19	1	0	.73	.42	.455	16.83	160	.35	17.3	.0750
Pastured abandoned agricultural land	1.80	10	0	.18	1	30	.62	.48	5.328	316.20	60	.65	10.783	.7610
Forested	1.84	9	15	.20	1	32	.61	.47	30.74	25.42	220	.35	773.95	.1134
	2.10	10	45	.20	2	0	.52	—.34	2.116	14.98	360	.25	90.4	.0935
	2.17	10	45	.20	2	0	.51	.34	2.167	19.40	255	.29	71.5	.1046
Abandoned agricultural land	1.97	10	40	.18	1	37	.56	.45	3.945	155.4	65	.61	16.25	.3980

[1] Recorded peak flow in cubic feet per second.
[2] Mean rate of precipitation during time of concentration.
[3] Area of watershed in acres.
[4] Watershed constant, indicating ratio of run-off to rainfall. It is an expression of the combined factors of slope, shade, cover, soil, geology, etc. Note the following equation

$$C=\frac{Q}{IA}$$

TABLE 14.—*Storm flow in percentage of precipitation, for 6 storms on 3 watersheds, Bent Creek Experiment Forest*

Date of storm	Watershed No. 2 (forested: Area 17.30 acres)			Watershed No. 8 (abandoned agricultural land: Area 16.25 acres)			Watershed No. 3 (pastured abandoned agricultural land: 10.78 acres)		
	Precipitation during storm	Peak discharge per square mile	Storm flow in percentage of precipitation	Precipitation during storm	Peak discharge per square mile	Storm flow in percentage of precipitation	Precipitation during storm	Peak discharge per square mile	Storm flow in percentage of precipitation
1936	*Inches*	*Cubic feet per second*	*Percent*	*Inches*	*Cubic feet per second*	*Percent*	*Inches*	*Cubic feet per second*	*Percent*
Jan. 6–11	2.25	4.5	5.7	2.47	51.5	8.1	2.38	97.2	19.2
Jan. 18–22	3.45	15.8	11.4	3.50	88.5	19.6	3.23	104.8	25.2
Mar. 23–31	3.86	17.8	16.5	3.83	109.0	11.4	3.63	231.3	22.6
July 2	1.30	23.5	1.5	1.34	403.0	15.4	1.29	750.0	23.5
Aug. 10	1.15	20.8	2.4	1.17	326.8	8.4	1.12	756.2	16.9
Oct. 14–19	4.48	27.7	13.3	4.60	208.3	30.0	4.23	368.1	43.5

The consequences of the destruction of vegetative cover and the almost universal system of exploitative agriculture are summarized by Bradfield (*13*):

> Our forests have almost completely disappeared and with them their dense canopies and their protective influence on soil processes. The leaf litter, after the annual supply was cut off, was mixed with the soil and the rate of decomposition accelerated. It soon disappeared save for a small humus residue. The roots were killed but, being resistant to decay, kept the soil loose for a few years, but eventually became fragile and disintegrated and decomposed under the combined attack of microorganisms and the physical and chemical weathering agencies, both of which were aided and accelerated by tillage operations. The larger, deeper roots of the trees lasted longer, but they too gradually decayed, their channels serving as drainage tubes temporarily, but they were gradually occupied by other roots and eventually filled by the washing in of surface soil. In the more rolling sections the truncated soil profiles give unmistakable evidence of the loss of the more fertile surface horizons by sheet erosion even where there is no other visible evidence of the more striking forms of erosion. As a result of the destruction of these organic residues, biological activities have been reduced, the natural structural aggregates have been destroyed, and the soil particles tend gradually to assume a position of closer packing. In many cases from 25 to 30 percent more soil is crammed into a cubic foot than was present in the virgin soil. This has reduced porosity, especially the volume of larger pores through which water penetrated readily and through which the soil received the necessary ventilation. As a result of these changes in structure, root development is hampered, the storage capacity of the soil for water is reduced, flood hazard is increased, and the damage from frequent periodic droughts is magnified.

FIRE DAMAGE

Fire is perhaps the most widespread and destructive disturbing agency of natural cover. Even the lightest running fire consumes some of the inflammable materials, including the litter, whereas the more severe fire may consume practically all the combustible material, including that in the surface soil. In any case there is destroyed the enormously important protective soil covering, a chief factor in the forest's favorable influence on run-off and erosion. In some forest types the litter commonly is entirely consumed by periodic ground fires that cause no spectacular damage to the standing trees. Fires hot enough to consume the litter also destroy part of

the humus in the topsoil and thereby affect adversely its loose, porous, granular structure.

A number of investigations have been made of the interrelation of fire and run-off in characteristic chaparral-covered watersheds in southern California, which, when subjected to hot summer or fall fires, are usually swept almost clear of plant cover. If the subsequent fall and winter precipitation comes as mild, well-sustained rains, a cover of annuals will come in, which, together with sprouts from the living burned-off shrubs, usually is sufficient to hold most of the soil in place. However, semitorrential downpours of rain frequently occur before an adequate cover is reestablished, and the rapid unobstructed run-off sluices great quantities of soil from the slopes.

A disastrous flood swept out of Verdugo and Haines Canyons in Los Angeles County, Calif., on January 1, 1934, causing the loss of 34 lives. The flood flow was more of mud than water. The results of a special study of the flood, made by the California Forest Experiment Station, are summarized in table 15. The storm that caused the flood extended over a 50-mile belt of foothills and mountains and the rainfall averaged more than 10 inches in a period of 2½ days. The watersheds in which the destructive flood originated, totaling about 4,000 acres in area, had been partially burned over only a few weeks earlier. The maximum flood discharge from the two drainage basins reached 1,000 cubic feet per second per square mile. Erosion debris removed amounted to 50,000 to 67,000 cubic yards per square mile. Neighboring watersheds subjected to the same rainfall, but with their forest cover intact, yielded clear water which caused no unusual erosion and did no damage. The run-off in unburned San Dimas and Arroyo Seco Canyons, a few miles distant and subjected to approximately the same rainfall, was only 51 to 58 cubic feet per second and carried only 56 cubic yards of eroded material per square mile. The relations between cover conditions and the character of the stream channels immediately after the storm are shown in figure 11.

TABLE 15.—*Run-off and erosion from unburned and burned parts of 4 watersheds, storm of Dec. 30–31, 1933, and Jan. 1, 1934, Los Angeles County, Calif.*

Watershed	Rainfall for storm	Watershed area	Portion of total area—		Maximum run-off per square mile	Eroded material per square mile
			Unburned	Burned		
	Inches	*Square mile*	*Percent*	*Percent*	*Cubic feet per section*	*Cubic yards*
Verdugo	12.56	19.13	67	33	1,000	50,000
Arroyo Seco	12.32	16.24	99.4	.6	58	
San Dimas	10.82	16.85	100	0	51	56
Haines	11.26	1.45	68	32	1,000	67,000

A fire in 1927 burned over 704 acres of the watershed above Burbank, Calif. The next year, with only 1.07 inches of rain in 3 hours, but with a maximum intensity of 1.70 inches per hour for about 10 minutes, surface run-off was three times as great as on adjacent unburned canyons. Between 25,000 and 50,000 cubic yards of eroded material was swept off the burned watershed, while no noticeable erosion took place on adjacent unburned canyons.

A comparison of the debris and erosion from similar burned and unburned watersheds in southern California during the 1935–36

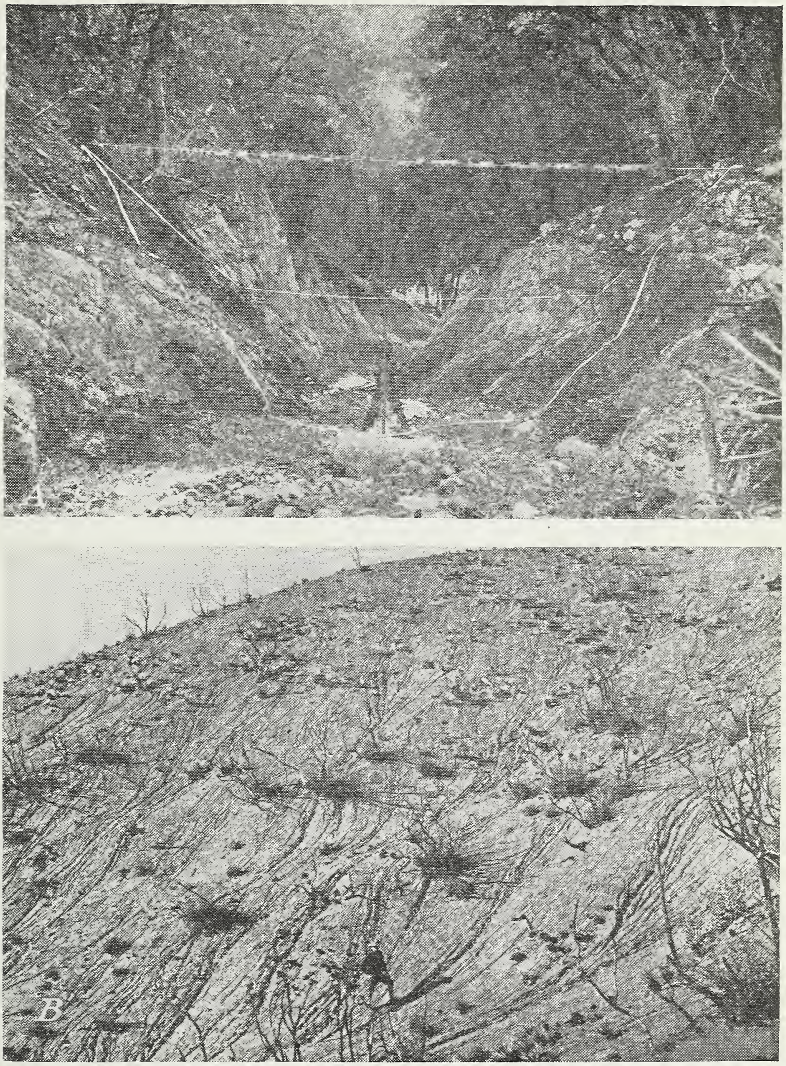

FIGURE 11.—*A*, The burn on the watershed (below) permitted flash floods which deepened the channel of the stream (above). The center line indicates the depth of the channel before the burn occurred. Compare this pair of pictures with figure 13, showing a stream from an unburned portion of the watershed. *B*, The line across the stream (above) shows the height of the crest of the flood during a 10-inch rain on the unburned portion of the watershed (below).

season is shown in table 16. The burned watersheds were denuded by fires on October 23, 1935. In contrast to these are the nearby unburned chaparral-covered watersheds. The results show that removal of native vegetation contributes importantly to floods and excessive erosion.

TABLE 16.—*Debris and erosion measurements from burned and unburned watersheds, southern California, in 1935–36*

Watersheds	Area	Total erosion and debris	Rate of accumulation per square mile
Burned:[1]	*Square miles*	*Cubic yards*	*Cubic yards*
Fair Oaks	0.21	15,715	74,830
Fern Canyon	.50	15,120	30,240
Lincoln	.50	7,960	15,920
Las Flores	.32	10,630	33,220
West Ravine	.25	18,335	73,340
Unburned:[2]			
Bell No. 1	.121	[3] 79	652
Bell No. 2	.158	10	63
Bell No. 3	.097	[4] 68	701
Fern No. 1	.055	.3	5.4
Fern No. 2	.063	.1	1.6
Fern No. 3	.084	.1	1.2

[1] The burned watersheds were denuded by fire on Oct. 23, 1935. Records from debris basins, Los Angeles County flood control district.

[2] The "unburned" areas in Bell Canyon were burned over in 1919, and now are covered with a growth of chamise-Ceanothus chaparral. The Fern Canyon watersheds have not been burned over in at least 60 years, and are now covered with a heavy stand of scrub live oak, big cone spruce, and manzanita-buckthorn chaparral. The Bell and Fern Canyon areas are in the San Dimas Experimental Forest. Records from San Dimas Experimental Forest, U. S. Forest Service.

[3] Eroded material came in large part from a road-fill not yet completely stabilized.

[4] Erosion traced to natural slumps not far above reservoir.

Stream flow may increase temporarily after burning over a watershed but this increase is of questionable value because of its quality. Hoyt and Troxell (*33*) compared the run-off of Fish Creek in southern California with that of Santa Anita Creek, the neighboring watershed, for the 7-year period from October 1917 to September 1924, when both were covered with forest and chaparral, and then for the 6-year period following a fire in the fall of 1924 which denuded the Fish Creek watershed. In the first year following the fire there occurred a 231-percent increase in run-off over the estimated normal of 1.07 inches and an increase of 1,700 percent in the maximum daily discharge from the first four storms after the fire. The flood peak, which was ordinarily 2.5 times the maximum daily discharge prior to the fire, increased to 16.2 times on April 4, 1925. During the second year after the fire they noted an increase of 26 percent above the estimated normal in the run-off from Fish Creek and during the 6-year period after the fire an average annual increase of 29 percent. Blaney has attributed this increase not to the chaparral, which constitutes 97 percent of the watershed, but to the removal by the fire of the riparian forest cover, of a high water-consuming capacity, in the canyon bottom.

Hoyt and Troxell further pointed out that under normal conditions, erosion in the watersheds of Fish Creek and adjacent creeks was negligible, but that samples of water collected from those streams during 4 months immediately after the fire showed a total sand and ash content of 20 to 67 percent by volume and 6 to 40 percent by weight. They state also that in the first month after the fire

the large deposit of silt from the burned-over area caused considerable damage to orchards, railroads, and highways adjacent to the mountains.

The increase in stream flow which resulted from the burning over of the watershed was in a large measure offset by the sediment carried in the water, especially immediately following the fire. As pointed out by Cecil, in discussing the usability of water from southern California watersheds:

> The prime requisite in water production is that water must be usable. This factor is of greater importance than the quantity produced and is vastly more important than a minor increase in the sustained summer flow * * *. The replenishment of these underground reservoirs * * * is of paramount importance. For years past, several communities have spread the floodwaters over detrital cones by means of lateral ditches, increasing the wetted area and materially increasing percolation over that obtaining under natural conditions. The experience of these communities has proved beyond a doubt that, in order that water may be spread successfully and the maximum of percolation secured, it must be free of suspended matter. It is often necessary, during the first run-off of the season, to bypass to the ocean a varying part of the flood flow. In the case of a watershed that has been run over by fire, the quantity that must be bypassed because of the silt load is many times as great as that under normal conditions.

Before the 1924 fire on Fish, Sawpit, and Rogers Creeks practically all the run-off of these streams was either used for direct irrigation or went to replenish underground reservoirs as described by Cecil. After the fire, much of the run-off in 1925 could not be used because of its content of debris.

Under the semiarid conditions of southern California it ordinarily takes not less than 5 years for enough vegetation to be reestablished on burned watersheds to serve effectively in controlling semitorrential rains. In instances where much of the productive topsoil is washed from the slopes as a result of hard rains in the first year, it takes considerably longer than 5 years. This had led the Forest Service to sow black mustard seed on burns in national forests in order to obtain a quick cover (fig. 12) to reduce run-off and erosion.

In the pine region of the Sierras, a 5-year record of the run-off and erosion from repeatedly burned and comparable unburned plots has shown a yearly run-off from the burned area ranging from 31 to 463 times that from the unburned, and yearly erosion ranging from 22 to 239 times that from the unburned. The run-off from a plot allowed to revegetate after a single burning exceeded the run-off from an unburned check plot by 31 times the first year, and by 11, 5, 15, and 14 times in the subsequent 4 years. After carrying off 485 times as much eroded material as the check plot the first year, run-off in the second year carried only 81 times as much. Analysis of the surface soil revealed that the average volume weight from the annually burned plots was 10 percent greater than that of the topsoil from the undisturbed plots.

A marked effect of fire on stream flow also was noted under the somewhat more humid conditions in the northern Rocky Mountains. About 18 percent of the Clearwater River drainage, largely timbered, above Kamish, Idaho, was burned over in 1919. It reclothed rapidly with a fair cover of brush and herbaceous vegetation. An analysis of the stream-flow records of the United States Geological Survey and climatological data of the Weather Bureau for the Clearwater River and drainage basin for 10 years, 5 years before and 5 years after

the fire, indicates a higher but much less equable flow in relation to precipitation following the fire. The average date of peak flow of the Clearwater after the fire was advanced by 14 days, in contrast to a 2-day advance in the neighboring Salmon River, the drainage of which had suffered much less from fire. The average flow of the Clearwater on the peak days for the 5 years after 1919 was 9.5 percent greater than it was before the fire, in spite of the fact that the highest peak of the 10-year period occurred before the burning in 1917 as a result of exceptional rainfall in April and May. Furthermore, the April to June run-off increased from 66 percent of the total annual flow to 73.5 percent, and the July to September run-off decreased from 13 percent of the yearly flow to 9 percent. In other words, after the fire the spring flood was 11 percent greater than before the fire, and the summer run-off was 32 percent less. April to

FIGURE 12.—Black mustard forms a dense cover in a few weeks after sowing, preventing erosion and retarding run-off. The triangular area escaped seeding and continued to discharge water after each rain. The mustard-covered area did not.

June flow is chiefly the result of surface run-off from melting snow, whereas July to September run-off results almost entirely from the slow drainage of ground water. The fires increased the spring flood flow at the expense of summer flow.

Results similar to those obtained in the far West have been noted elsewhere in the United States. For example, studies were made on two plots in post oak timber near Guthrie, Okla., during a period of almost continuous rainfall in May 1932. On one plot, the forest litter had been burned, while on the other, immediately alongside, the natural ground cover of leaves and twigs had been left undisturbed. Marked differences of run-off and erosion were evident. Run-off from the unburned plot was clear and totaled 250 gallons an acre; that from the burned plot, having the same soil and slope, was muddy and amounted to 27,600 gallons an acre. The excess of

run-off from the burned area over that from the unburned area, plus the 16.7 tons absorbed by leaf litter itself, was approximately 90 tons an acre. From the burned plot an average of 0.15 tons of soil per acre per year was eroded, and from the unburned plot 0.01 ton.

Similar studies in the eastern mountains made at the Appalachian Forest Experiment Station show that removal by fire of the litter under an old growth pine-hardwood forest resulted in surface storm flow averaging 10 times as great as that on adjacent unburned control plots with differences as great as 32 times for individual storms.

Logging

The common commercial practice on most of the 10 million acres of forest annually cut-over in the United States is a very close approach to clear cutting. Through a combination of cutting and fire about 850,000 acres of this area are devastated each year; that is, they are left in such condition that they are incapable of producing another commercial crop of timber within a tree generation. The greater part of this area is left almost devoid of standing trees, particularly in the softwood forest regions of the South and West. On some of the eastern hardwood land there may remain a considerable residual stand—of low value as a source of wood but very useful as a watershed cover.

Logging alone, if neither preceded nor followed by fire, destroys a smaller proportion of the understory of young trees and shrubby species than of the main stand. Critical areas, however, are still being logged by high-powered machinery that drags logs over the ground and destroys much of the lesser vegetation, in some places nearly obliterating the litter.

On a clear-cut area there is no longer appreciable interception of precipitation by tree crowns, and little high shade to retard snow melt or prevent evaporation. There may be, however, some shading of the ground by slash. This, in such conifer types as Douglas fir, western white pine, southern white cedar, or red spruce, may cover practically 100 percent of the ground. After a year or two this slash itself may become powder dry, but it continues to exert some beneficial effect on evaporation from the soil.

The time that must elapse before surface conditions on cut-over land are restored by reforestation to approximately what they were before cutting varies widely with forest types and degree of cutting. In many forest types, clear-cut areas are very abundantly invaded within a season or two by herbaceous plants. These at least serve to check erosion and start to rebuild the extremely important litter. A sprout forest tends to restore cover conditions more promptly than most seedling forests, because of the early vigorous growth.

The effect of clear cutting in a forest subsequently regenerated by sprouting species is demonstrated, for a single condition, by the results of a watershed study at the Wagon Wheel Gap in the high mountains of Colorado (*7*). The stream flow from two adjacent watersheds was measured under undisturbed conditions for 9 years, 1910 to 1919. The forest on one watershed was then cut and the measurements were continued. A dense cover of aspen sprouts took possession of the area the first year after clear cutting. The total yearly run-off during the next few years was increased by about 15

percent and the summer run-off was increased by about 10 percent. This increase is chiefly attributed to the recovery as stream flow of the precipitation formerly lost by interception by the coniferous forest cover in the original timber stand, because the total increase in flow and former interception losses are approximately equivalent to each other. Flood crests, however, were advanced about 3 days and the maximum height of crest averaged 64 percent greater in the cut-over area than in the undisturbed watershed. Since the height of the flood crest from the cut-over area prior to logging exceeded that from the undisturbed area by 6 percent, the net increase in flood crest is calculated to have amounted to 58 percent. The silt load of the stream after logging increased 7½ times.

It is apparent that the method of managing forest stands, especially coniferous forests, has an important bearing on the outcome of quantity and character of stream flow, and is an important consideration where quantity as well as regularity of flow is involved. By regulating the timber cut so as to maintain the proper mixture of various size classes it should be possible to retain most of the benefits of forest cover in relation to absorption of surface water, reducing evaporation, and retarding snow-melt, and at the same time to avoid excessive loss by interception. Further research is needed to develop the methods of cutting and logging in order to obtain the greatest net benefits in regulation of run-off, in maximum yields of usable water, and timber production.

Overgrazing

The exploitive use of range and pasture lands of the country has not only greatly reduced their utility for grazing, but has also greatly changed conditions with respect to run-off and erosion.

ON WESTERN RANGE LANDS

If not utilized too closely each year, the ground cover of grasses, weeds, and shrubs on range lands will be fairly well maintained except in an occasional drought year. However, grazing will reduce the quantity of plant cover and the concomitant trampling will compact the soil. That these effects will greatly modify run-off characteristics has been shown by various studies.

Table 17 summarizes the results of a study of two watersheds, each approximately 10 acres in size, near the summit of the Wasatch Plateau in central Utah. The first 15 years of this study have been summarized in a Department publication (*27*). It was found that the major portion of the run-off was derived from winter snow, but that by far the greater amount of erosion was caused by summer rains. As a result of allowing the vegetal cover on watershed A to increase from 16 percent in 1920 to 40 percent in 1924, the summer run-off was reduced 64 percent, and the amount of silt lost was reduced 54 percent (fig. 13). Since 1934 the area has been overgrazed so as to reduce the cover below 40-percent density. In 1936 this density had been reduced to approximately 25 percent. In 1936, following the heaviest summer rainfall since measurements were started, there occurred the greatest run-off of record for a single summer season, on both areas. As shown by a comparison

of the A–B ratios for 1936, with those of previous years, the amount of run-off and erosion were both greatly increased on watershed B as a result of the reduction of cover and trampling incident to the overgrazing since 1934.

TABLE 17.—*Percentage of ground occupied by vegetal cover, surface run-off and silt eroded per acre for summer rainstorms from watersheds A and B at the great Basin Branch Experiment Station, Utah, between 1915 and 1936*

Periods	Watershed A			Watershed B			A–B ratio	
	Ground having vegetal cover	Run-off	Silt	Ground having vegetal cover	Run-off	Silt	Run-off	Silt
	Percent	*Cubic feet*	*Cubic feet*	*Percent*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
1915–20	16	912.6	133.82	40	153.1	24.67	5.96	5.42
1921–23	16–40	921.8	105.03	40	260.6	37.30	3.54	2.82
1924–29	40	297.1	19.15	40	137.4	7.73	2.16	2.48
1929–34	40	216.8	4.56	40	82.9	1.59	2.61	2.87
1936	40	4,057.4	154.25	[1] 25	4,042.0	100.52	1.00	1.54

[1] The density of the plant cover on watershed B was not determined in detail in 1936, but experienced observers estimated it to be 25 percent of a complete cover.

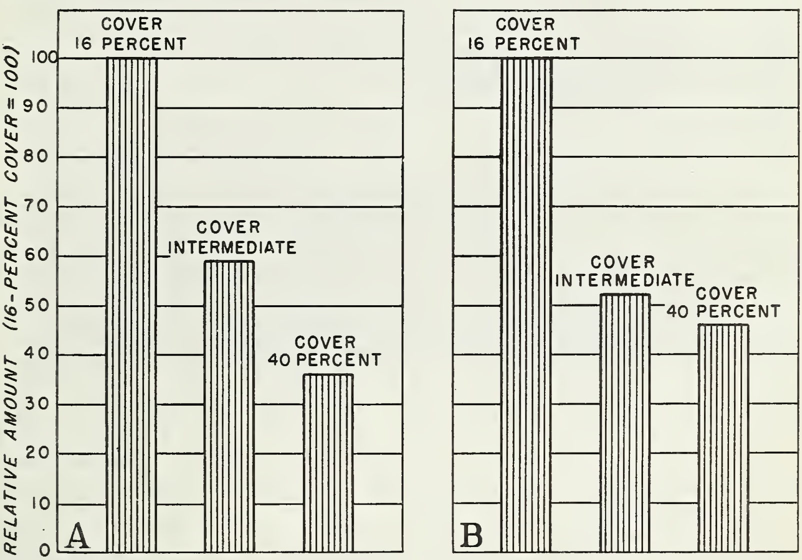

FIGURE 13.—Comparison of surface run-off (*A*) and sediment eroded (*B*) from lands under 40 percent, 16 percent, and intermediate plant cover.

Data obtained in the summer of 1936, from 16 superficial run-off plots on 1 of the watersheds from which floods came in 1930, are summarized in table 18. These results show that superficial run-off and silt loss from the 6 plots with an annual weed cover of 4-percent density and 6 browse areas of similar size with a density of 8.1 percent, both plots lacking a litter cover, was much greater than from the 4 adjacent aspen plots having a complete litter cover and a plant density of 14.5 percent.

TABLE 18.—*Quantity of run-off and soil loss from experimental plots with 3 different cover conditions resulting from 5 rainstorms in the summer of 1936, with a precipitation of 4.3 inches of rain, Davis County, Utah.*

Conditions	Rainfall	Plant density [1]	Run-off in percent of precipitation	Soil loss per acre
	Inches	*Percent*	*Percent*	*Cubic feet*
Open aspen forest with heavy litter (average of 4 1/40-acre run-off plots on 22 percent-slope)	4.38	14.5	0.47	[2]
Annual weed type, no litter (average of 6 1/40-acre plots on 22-percent slope)	4.38	4.0	35.03	457.60
Browse type,[3] no litter (average of 6 1/40-acre plots on 30-percent slope)	4.38	8.1	26.74	376.00

[1] Under cover only.
[2] Only clear water reached the tanks.
[3] At present, the cover largely consists of annual weeds, the result of past fires and overgrazing.

For the past 40 years floods of a severity to which boulder-strewn fields and valleys bear evidence, have been occurring with increasing frequency over the entire length and breadth of Utah. Between Ogden and Salt Lake City 15 canyons in the Wasatch Mountain front have within the past few decades produced such floods—each originating on depleted, privately owned range lands representing a total of only a few hundred acres and but a small portion of each individual watershed. In 1923, and again in 1930, floods and mud-rock flows pouring forth from certain of these canyons probably exceeded anything which had occurred in that area for at least 20,000 years. Boulders weighing as much as 200 tons were carried into the valley, farm lands were ruined, homes and other improvements were destroyed, and lives were lost.

After the floods of 1930 the Governor's special flood commission established the fact that the waters heavily laden with silt had collected chiefly on small areas of private land at the heads of the drainages where the vegetative cover had been destroyed or become seriously depleted by overgrazing, fire, and to some extent by logging (*6*). These areas are badly gullied and the surface soil has been stripped away. At intermediate elevations slopes too steep for grazing make up the greater part of the mountain face. These bear a substantial brush or forest cover. No gullies originated on these densely vegetated slopes, where the thick litter cover and the large humus content in the surface soil permitted effective penetration of water and restrained the surface flow sufficiently to prevent undue soil or water losses.

On the Boise River watershed in Idaho studies with a portable apparatus for simulating natural rainfall (fig. 14) have demonstrated the value of vegetation in preventing erosion and conserving water on the granitic soils of that region (*20*). The effect of varying intensities of rainfall, degree of slope, and disturbance of the soil were determined on comparable plots within four plant types. Run-off and erosion from rainfall were negligible where the bunchgrasses—the highly palatable, virgin range cover characteristic of south central Idaho—predominated. Both run-off and erosion were pronounced where other plants had succeeded bunchgrass because of overgrazing. The greatest run-off and the largest amount of eroded material come from annual weed cover—a plant cover that is an infallible expression of overutilization.

A many-branched, fibrous root system is an important factor in retarding soil removal and aiding absorption. The bunchgrass type, which has the greatest forage value of any local range type, and to which most of the grazing land in the area will ultimately revert if unabused, yielded only 0.4 percent run-off and 6 pounds of eroded material an acre. The downy chess and needlegrass-lupine types, which have succeeded the bunchgrass on overgrazed ranges at lower and higher elevations, respectively, are distinctly less effective watershed covers. On the average, 25.5 percent of the precipitation on the downy chess cover and 47.6 percent on the needlegrass-lupine cover was unabsorbed, and the run-off washed off an average of 2.017 and 4,785 pounds of soil per acre from the respective types. An annual weed type afforded the least protection, permitting 60.8 percent of the applied water to run off, which transported the equivalent of 15,280 pounds of soil an acre. Figure 15 illustrates the char-

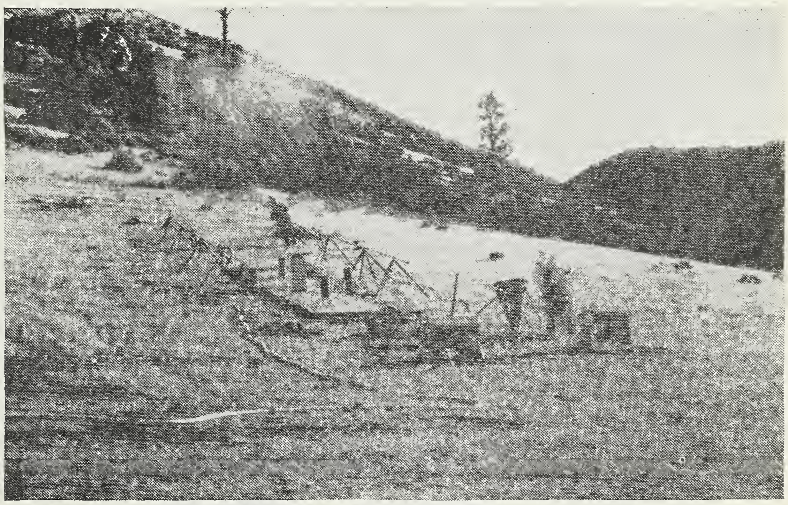

FIGURE 14.—By using a portable artificial "rainmaker" it is possible to obtain run-off data for rains of different amounts and intensities under a variety of conditions.

acteristic root systems of the plants of the various types and indicates that in this region a dense mat of fine roots near the surface of the soil serves best in protecting the soil from erosion and in obtaining maximum absorption.

Definite correlation between grass cover and losses of soil and water is revealed in studies by the Southwestern Forest and Range Experiment Station. Annual run-off and soil erosion were measured from a grass range cover representing three degress of depletion on a 25-percent slope. With the range cover approximately 25 percent depleted, 22 percent of the annual precipitation was surface run-off and the equivalent of 109 cubic feet of soil an acre was eroded. With the cover approximately 50 percent and 75 percent depleted, surface run-off was 28 and 32 percent, respectively, of the annual precipitation, and soil eroded an acre was 174 and 240 cubic feet, respectively.

In a survey of the upper Rio Grande drainage in New Mexico above Elephant Butte Dam accelerated erosion was found within all of nine vegetative types. Within this area only 25 percent of the watershed is in fair to good condition, 35 percent is characterized by advanced erosion, and 40 percent by excessive erosion. The watersheds of the Rio Grande tributaries below Embudo, N. Mex., have a badly depleted cover of range vegetation and discharge enormous quantities of silt and floodwater into the main channel. This silt, carried down and deposited in the low gradient channel of the Middle Valley, has so built up the channel as to slow down the flow of the river, causing the water-logging of 80,000 acres of formerly productive farm land.

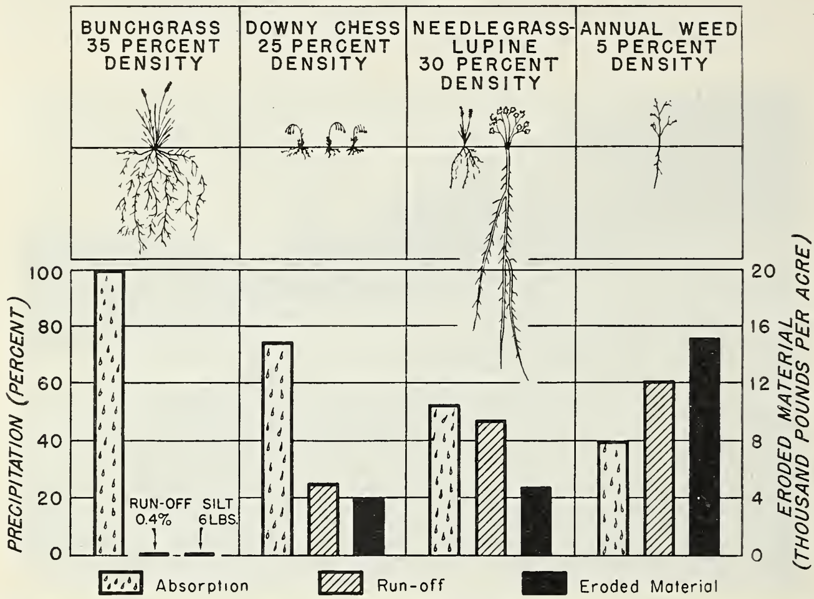

FIGURE 15.—A dense mat of fine roots near the surface of the soil serves best in protecting the soil from erosion and in obtaining maximum absorption.

Other studies by the Southwestern Forest and Range Experiment Station, on the Salt River watershed in Arizona, show that an average of 432 cubic feet per acre of topsoil and soil-forming materials is lost annually from typical deteriorated brush ranges.

On mesa areas, such as those on the Navajo Indian Reservation, great sheets of surface soil from the grassland have been blown or washed away as a direct result of grazing abuse, and arroyos 30 to 50 feet wide and 10 to 20 feet deep, with tributary gullies 8 feet wide and 5 feet deep, are common where originally only shallow streambeds and depressions were present. The higher plateau grazing areas which have been used with no regard to watershed values have been severely channeled. The lower Rio Jemez drainage is a typical example. Here arroyos have been cut through at least 25 percent of the meadows, and 40 to 50 percent more are in the process of cutting.

ON FARM WOOD-LOTS

In pastured farm woodlands of the Middle West, studies by the Central States Forest Experiment Station show that grazing results in the destruction of the sprouts of hardwood timber species, and that trampling of the livestock tends to destroy the litter and compact the soil, making it less receptive of precipitation and subject to erosion. Under extreme use, such as occurs in the Corn Belt where many farm woodlands are used as much for shade as for the feed they produce, practically the entire understory of vegetation and the litter covering the soil have been destroyed. When such a situation has developed on rolling lands, the topsoil is invariably lost.

From a plot in pastured oak woodland with a slope of 38 percent, 13 percent of the rain ran off, while from a dense unpastured oak forest with a slope of 42 percent only 0.2 percent ran off and only 2 percent from open unpastured oak woods with a slope of 49 percent ran off (*8*).

Weaver and Noll (*57*) in a study of the water relations of barren, grazed, and fully vegetated soils obtained similar results. From barren soils 15.1 percent of the rainfall ran off, from the pastured areas 9.1 percent, and from the area with a full vegetative cover only 2.5 percent. Five days after heavy artificial applications of water, moisture had penetrated to 19 inches in the bare soil, to 22 inches in the pastured soil, and to 42 inches in the soil supporting the full prairie vegetation.

Auten has shown in his studies of grazed and ungrazed areas in Ohio and in the Ozarks that the top layers of grazed soils averaged 15 percent heavier than those of ungrazed soils. The heavier and more compact soils, moreover, were distinctly inferior to the light, porous soils from ungrazed woods in ability to absorb repeated applications of water. The reduced absorptive capacity of soils from grazed woodlands reflects the lack of litter which characterizes such areas fully as much as the destruction of surface network of roots and packing of the soil by trampling of livestock.

The work of Stewart (*48*) reveals the same tendency in New York State of long-continued grazing to reduce permeability and water storage of soils.

The results of experiments at the Upper Mississippi Erosion Station at La Crosse, Wis., contribute tangible evidence of the part which cleared pastures and grazed and ungrazed wood lots play in relation to run-off and erosion on steep slopes. Three small watersheds have been selected: (1) A pasture recently cleared of timber; (2) a watershed covered with typical hardwood forest that is being pastured; (3) a typical wood lot upon which no grazing of any kind is permitted.

In the calendar year of 1935 there occurred eight storms of rather high intensity, although the precipitation for the year was not markedly above the normal of 30.81 inches. From August 1 to 6 several successive storms caused one of the worst summer floods experienced in southwestern Wisconsin in several decades. That year, therefore, was an especially good one to test the effectiveness of the different types of vegetation and land use on run-off and erosion.

Of the total rainfall occurring during the period May to November, the recently cleared pasture yielded 3 percent in the form of run-off.

The grazed wood lot yielded about 9 percent run-off, and the ungrazed timbered watershed, only 0.15 percent run-off. The soil washed away during the same period amounted to 600 pounds an acre for the cleared pasture, 1,600 for the grazed wooded watershed, and 17 for the ungrazed timbered watershed.

The quantity of run-off and the amount of soil eroded from the three watersheds varied with the intensity of each storm. Thus, during the 4-hour storm of August 5, when some 2.4 inches of rain fell, the cleared grazed watershed yielded 6 percent of the pecipitation in the form of run-off, the grazed-wooded watershed 17 percent, and the ungrazed wooded watershed 0.7 percent. The soil loss dur-

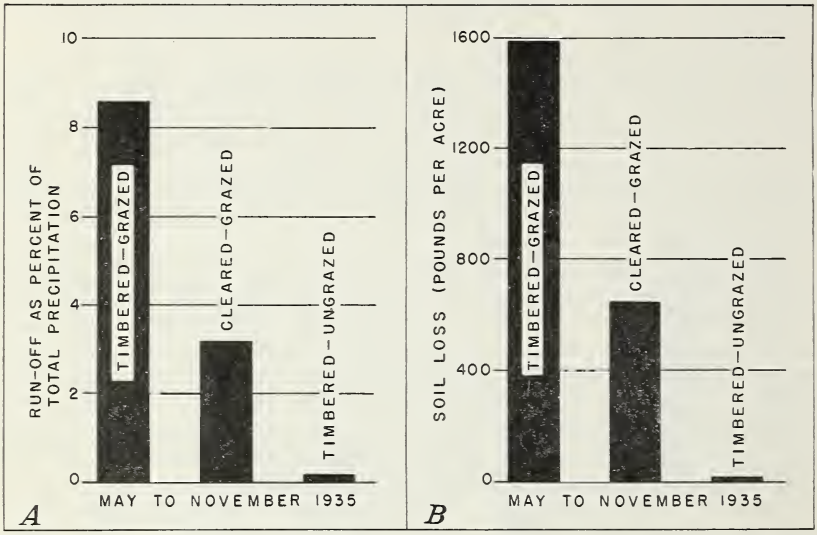

FIGURE 16.—During the eight most intense rains at La Crosse, Wis., run-off (*A*) and soil loss (*B*) occurred only twice from an ungrazed wooded watershed, and then in quantities so small as to be insignificant.

ing this same storm amounted to 220 pounds an acre for the cleared pasture, 745 pounds an acre for the wooded and grazed pasture, and only 17 pounds an acre for the ungrazed wood lot.

During the eight most intense storms of the summer of 1935 run-off and soil loss occurred only twice from the ungrazed wooded watershed and then in quantities so small as to be insignificant (fig. 16).

DENUDATION BY SMELTER FUMES

Completely denuded areas are of interest because they present the extreme consequences of destruction of plant cover. Fumes from smelters and other industrial plants may completely destroy or injure forest and other vegetation. Complete denudation by smelter fumes may be seen near Ducktown, Tenn., Kennett, Calif., Anaconda and Butte, Mont., and in the vicinity of other smelters located within

forested areas. At Ducktown (fig. 17) the smelter fumes have killed all the natural vegetation in an area of 10 to 12 square miles, except for occasional clumps of sage grass and wild smilax. Bordering this barren region is one varying from 1 to 5 miles in width, covered with sage grass, vines, and a few stunted shrubs and small trees, the latter often with dead tops. Beyond this border of almost treeless vege-

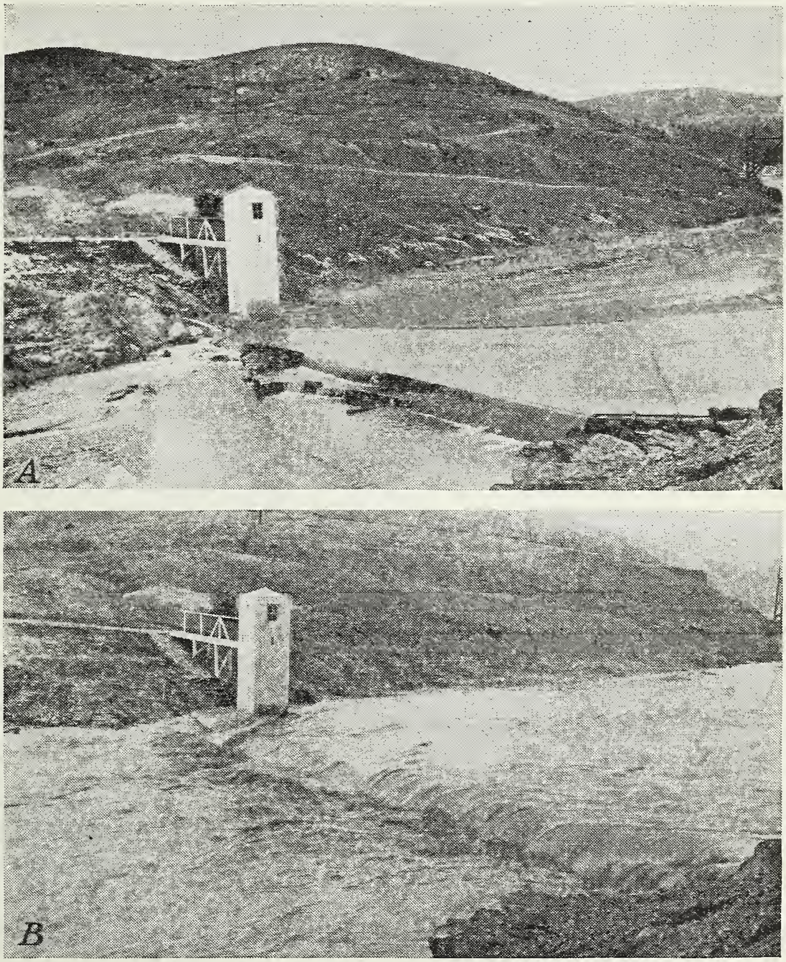

FIGURE 17.—*A*, Potato Creek at Ducktown, Tenn., in the smelter-denuded area before a storm. The tower is a United States Geological Survey gaging station. *B*, Potato Creek one-half hour after a ¾-inch summer rainstorm. Creeks rising in nearby forest areas were not in flood.

tation the country is not heavily wooded for some distance, the growth is unthrifty and trees with dead or dying tops are numerous.

Maximum rates of surface discharge of 1,263 to 1,434 cubic feet per second per square mile have been measured on plots on this area as compared with discharges during the same period of only 30 to 56 cubic feet per second per square mile from adjacent forested areas.

The storm of February 13 and 14, 1935, demonstrated the effect of the destruction of the forests in this region on the amount of soil that is eroded. During this 2-day storm 2.50 inches of rain fell. The maximum intensity was 0.15 inches in 20 minutes. Although not an intensive rain, it endured 14 hours. During this mild storm 8.3 tons of soil an acre was removed from a small denuded watershed of 15.6 acres. Soil removed from the forested watersheds in 2½ years of measurement has been an insignificant amount.

The annual rainfall in the region is 50 to 60 inches, and often torrential. Glenn (*29*) states that during downpours soil surfaces melt away. The wasted soil accumulates along the stream courses. He states further:

> On Potato Creek this waste has been accumulating for a number of years at the rate of a foot or more each year, and has been built into a flood plain from 100 to 300 yards wide, in which telephone poles have been buried almost to their cross arms, and highway bridges, roadbeds, and trestles have either been buried by the debris or have been carried away by floods. * * * The normal flow of Potato Creek is said to be only about half as large as it used to be, and there can be no question that a much larger part of the rainfall now finds its way immediately into this stream and is carried off in floods, leaving a much smaller part to soak into the ground to supply the wells, springs, and streams during periods of dry weather.

Near Kennett, Calif., all vegetation has been destroyed by smelter fumes on an area of more than 67,000 acres and partial destruction has occurred on 86,000 acres. Without the protection of vegetation, the surface soil soon washed off, exposing an inert subsoil which continues to wash and gully at a rapid rate. Munns (*43*) estimated a total of more than 35 million cubic yards of soil had been removed from the Kennett area in 10 to 15 years.

Conditions are similar in other smelter areas.

Silting of Reservoirs

The seriousness of the reservoir silting problem, particularly from an economic and engineering standpoint, deserves special consideration. There are more than 8,400 dams and reservoirs in the United States, and a conservative estimate would place the initial investment in these at more than $2,000,000,000. At least one-fifth of the number, representing probably three-quarters of the total investment, depend solely upon storage for their usefulness, and when storage is gone as a result of silting, their value will have largely disappeared. As soil erosion is known to be producing vast quantities of erosional debris in extensive areas of the country, and as surveys have already shown appreciable silting in a majority of reservoirs examined in these same areas, it is evident that soil erosion is an important factor in a problem which is Nation-wide in its importance. The rate of silting of representative reservoirs in the United States is shown in table 19.

Of 56 reservoirs examined by the Soil Conservation Service in the southern Piedmont in 1934, 13 major reservoirs with dams averaging 29.8 feet in height were found to have been completely filled by eroded material within an average period of 29.4 years.

TABLE 19.—*Silting of representative reservoirs in the United States* [1]

Name of reservoir	State	Age of reservoir at date of survey	Storage capacity lost by silting	Annual storage depletion
		Years	*Percent*	*Percent*
Burnt Mills	Maryland	7.8	46.47	5.96
Barcroft	Virginia	23.1	4.60	.20
Byllesby	do	23.7	60.21	2.54
Burlington	North Carolina	10.0	10.95	1.10
High Rock	do	7.8	4.81	.62
Spartanburg	South Carolina	8.2	17.15	2.09
Lancaster	do	13.4	21.49	1.60
Lloyd Shoals	Georgia	24.3	12.40	.51
Lay	Alabama	22.3	11.50	.52
Bayview	do	24.6	19.82	.81
Lake Decatur	Illinois	14.2	14.23	1.00
Lake Calhoun	do	11.9	52.10	4.37
Lake Taneycomo	Missouri	22.4	46.08	2.06
Guthrie	Oklahoma	14.5	14.88	1.03
Lake Spavinaw	do	11.0	3.71	.34
Lake Waco	Texas	5.9	19.78	3.35
Lake Medina	do	23.8	1.97	.08
Lake Austin [2]	do	13.0	95.40	7.34
Baker	Montana	29.1	33.60	1.15
Hayes Lake	South Dakota	4.2	7.79	1.86
Wellfleet	Nebraska	5.6	10.60	1.89
Meade County State Lake	Kansas	8.8	8.08	.92
Lake Olathe	do	4.9	10.34	2.11
Black Canyon	Idaho	12.0	10.72	.89
Elephant Butte	New Mexico	20.25	13.84	.68
San Carlos	Arizona	6.33	2.96	.47
Morena	California	25.7	10.50	.41
Santa Anita	do	10.2	34.52	[3] 31.53
Sherwood	do	31.0	2.72	.09

[1] U. S. Dept. Agr. Technical Bulletin 524, p. 142.
[2] Texas University Bulletin 3025, p. 38.
[3] Storage capacity lost during flood of Mar. 2, 1938.

In Texas some particularly severe silting has been measured. The reservoir behind Austin Dam at Austin, Tex., lost more than 95 percent of its original capacity of 32,000 acre-feet in 13 years. Lake Waco on the Bosque River, Waco, Tex., built for municipal water supply in 1930 with a capacity of 39,378 acre-feet, had lost over 14 percent of its original capacity in 1935. A resurvey made by the Soil Conservation Service 11 months later, in 1936, when the reservoir was still less than 6 years old, showed a total storage loss of 19.78 percent. This represents an average loss of 3.34 percent a year, but the actual loss during the last 11 months was 5.4 percent, apparently a result of heavy inflow more than double the normal annual rate for the preceding 10 years. A small basin-type municipal reservoir at Rogers, Tex., impounding 164 acre-feet when built, lost 23 percent of its capacity in 12 years. White Rock Reservoir at Dallas, Tex., lost 21 percent of its capacity in 25 years.

Ten water-supply and conservation reservoirs in the Great Plains region, having an average age of 9½ years, and an aggregate capacity of 12,360 acre-feet, were found by surveys of the Soil Conservation Service to have suffered an average annual loss of 1.20 percent. In one case the average annual loss was more than 2 percent.

On the other hand, studies recently completed by the Soil Conservation Service on the municipal reservoir at High Point, N. C., a $900,000 development, have shown a reduction in silting rate from 0.87 percent a year during the period 1928–34 to 0.42 percent during the period 1934–38, despite a higher average, and equally well-distributed rainfall during the latter period. This reduction is at-

tributed to the introduction of soil-conservation practices on 42 percent of the land in the drainage basin of the reservoir through the Demonstration Program of the Soil Conservation Service.

The economic aspects of reservoir sedimentation have been discussed briefly by Eakin (*25*) who pointed out that the damage involved is by no means confined to the original cost of the reservoir. Reservoirs are constructed at the most economical and physically favorable sites and consequently the development of additional storage to replace that lost by sedimentation is more costly and, in some instances, may not be feasible. Other developments dependent upon the reservoir will also be affected as the usefulness of the reservoir is impaired.

The cost of hydraulic dredging and mechanical removal of silt from reservoirs is, according to Eakin (*25*), prohibitive except for special-purpose dams where no alternative is possible. He states that the cost of silt removal would generally be 5 to 50 times as great as the cost of the original storage.

Recently Brown (*15*) has estimated on the basis of 81 sedimentation surveys by the Soil Conservation Service and other agencies that of all the existing reservoirs in the United States, 38 percent will have a useful life of only 1 to 50 years; 24 percent, 50 to 100 years; 21 percent, 100 to 200 years; and only 17 percent, more than 200 years.

Shoaling of Channels

Harmful sedimentation occurs not only where sediment loads are dropped in reservoirs, but also where the coarser parts of streamborne materials accumulate in the channels faster than the stream can remove them toward the sea, or toward a reservoir or lake basin (fig. 18). Such channel deposits tend to accumulate chiefly in places where the velocity of flow is decreased for any reason, as immediately above the heads of deltas or at the mouth of relatively steep tributaries which enter a master stream of markedly lower gradient. Such channel accumulations tend to cause more frequent overbank flooding, rising ground-water tables with consequent swamping of adjacent valley lands, and increased overbank deposition of silt and sand which may be harmful to the valley soils.

One of the most striking instances of the relation of channel sedimentation to flood control and land drainage problems is furnished by the conditions in the Middle Rio Grande Valley, in central New Mexico. A population of about 55,000 is dependent chiefly upon agriculture, which is possible only by irrigation from the waters of the Rio Grande. As part of a $10,000,000 irrigation project, extensive drainage canals and dikes for confining the flood flows of the Rio Grande have been built during the past 10 years, to be paid for by special taxes levied on the benefited lands.

Much of the drainage area tributary to the Rio Grande is natural range land, which has been heavily overgrazed and is suffering severe erosion. With the resulting increased sediment contributions to the river, which normally carried a heavy load as is the case with most streams in the arid southwestern region, the channel is filling up at an alarming rate, at least in the lower part of the Middle Valley, where the only accurate records are available. In the lower few miles of the valley, immediately above the head of Elephant Butte

Reservoir, which stores water for the successful irrigation projects farther downstream, the rising river bed has resulted in such severe flood damages and swamping of the valley lands that the town of San Marcial, which had a population of over a thousand prior to

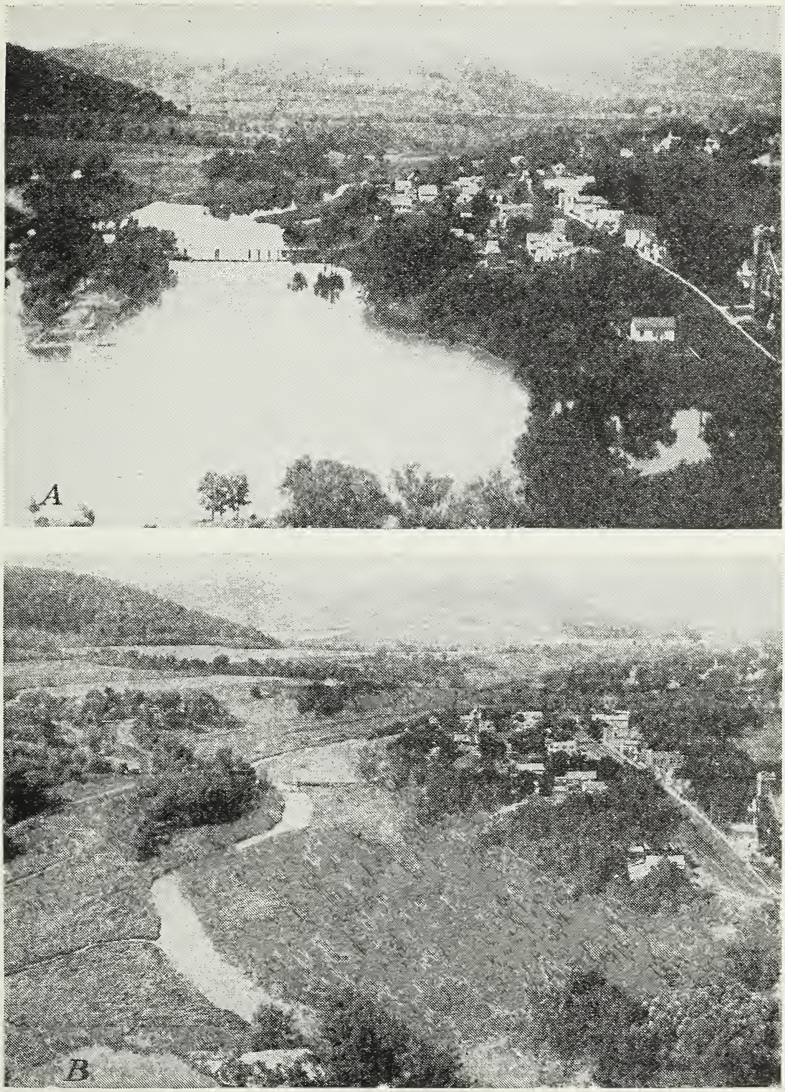

FIGURE 18.—*A*, In 1926 Lake Como at Hokah, Minn., was a popular resort for swimming and boating. *B*, In 1936 Lake Como was completely filled with sediment washed down from the cultivated watershed above.

1929, has since that date been almost completely abandoned. Since 1914, when Elephant Butte Reservoir was built, the bed of the Rio Grande a short distance above the reservoir limits has risen an average of about 13 feet, according to surveys made in 1936. Two

miles further upstream, and just above the San Marcial townsite, there was a rise of about 7 feet during the same period. In view of these conditions it is not surprising that dikes built to protect the town and adjacent irrigated lands have been repeatedly overtopped and broken by floodwaters, with disastrous results. The former irrigated fields west of the river were almost completely converted to swamps as a result of a severe flood in 1929, and in the spring of 1937 the Rio Grande broke out of the floodway to which it had been confined by dikes, and took a new course directly across the remaining irrigated lands lying east of the river.

Channel filling has also been rapid where the Rio Grande is joined by one of its principal tributaries, the Rio Puerco, some 50 miles above San Marcial. The Rio Puerco drains a large area of range land which is suffering severe accelerated erosion, and is delivering sediment to the Rio Grande more rapidly than the latter, which flows on a much lower gradient, can remove it. Consequently, the Rio Grande channel has been built up at rates as high as 9 inches a year, as shown by comparative surveys in 1927 and 1936. As a result, floodwaters in the spring of 1937 overtopped and washed out the levee and a paved highway, and converted hundreds of acres of pasture land into a sandy waste. Large parts of the former irrigated fields at the village of Contreras have become swamps, and in part even a lake, because the water cannot be drained into the river which is now flowing at a level above that of the fields. These conditions are of particular significance in that there has been measurably rapid aggradation of a restricted, yet relatively wide, floodway confined between levees.

Bailey and Connaughton (*4*), writing of conditions in the western range country, state:

> The watersheds of the Rio Grande tributaries below Embudo, N. Mex., have a badly depleted cover of range vegetation and discharge enormous quantities of silt and floodwater into the main channel. This silt, carried down and deposited in the low-gradient channel of the Middle Valley, has so built up the channel as to slow down the flow of the river, causing the waterlogging of 80,000 acres of formerly productive farm land.

Eakin (*24*) reported that sedimentation or shoaling in parts of the Yazoo basin has filled the original channels and valleys, in many places, to such an extent that the present-day flood flows must be carried through new flowage areas lying above the primeval flood plain.

The filling of artificial drainage canals is a serious form of channel sedimentation throughout a large area in northern Mississippi and western Tennessee. The valleys in this region are prevailingly wide and fertile, but subject to frequent flooding and in part poorly drained. In order to farm these productive lowlands, extensive drainage projects have been undertaken, but with little consideration of the effects of the severe soil erosion prevalent on the hilly parts of the drainage basins. Many of these canals have been largely or completely filled with sand derived from the eroding uplands, and have consequently failed to serve their intended purpose. In the Wells Drainage District in Lafayette County, Miss., three-quarters of the canals dug at a cost of $71,000 in 1920 were completely filled with sand by 1936, although special taxes to pay off the bond issue must continue to be collected at least until 1943. The rate of filling of the remaining canals has been estimated to amount to an average monthly

damage of $500, on the basis of the original investment, without including the damage to the adjoining valley lands.

On the upper Missisippi River, channel sedimentation involves heavy expenditures for dredging operations to maintain a navigable channel, and also contributes to flood damages on tributary valleys. Although accurate data are not available to show the rates of channel filling, numerous accounts of early settlers and old residents testify to the obviously large increase in turbidity of the streams that drain the adjoining uplands where soil erosion has been greatly accelerated since the clearing of forests and cultivation of the sloping lands. These streams now deliver large quantities of sediment to aggravate the problem of channel maintenance. In many cases the tributary streams bring down sediment more rapidly than it is removed by the Mississippi, and hence are building up the lower parts of the side valleys. In these areas of aggradation of the tributaries, many channels are inadequate to carry off floodwaters, and flood damage is excessive.

A comparison of maps of the Anacostia River between Bladensburg and Magruder Bridge, near Washington, D. C., has shown that in the 10-year period from 1865 to 1875, the bed of the upper 7,000 feet of the 11,700-foot river section was scoured from 1 to 3 feet deep and that the general level of the bed rose slightly in the remaining downstream section without appreciable change in the average width of the stream. From 1875 to 1891 there was, in general, a slight rise of the river bed, but from 1891 to 1937 a conspicuous rise amounting to approximately 3 feet occurred. The channel during this period has decreased from an average width of 70 yards in 1891 to approximately 25 yards in 1937. In 1891 mean low tide extended all the way to Bladensburg; in 1937, however, the limit of mean low tide was 1 mile below the town. These conditions show a marked progressive increase in the rate of channel sedimentation and suggest that it may be coincident with increasing soil erosion in the watershed. The conditions are indicative of the relation of soil erosion to the maintenance of navigable channels in estuaries of the southeastern Atlantic coast.

That channel sedimentation is a phenomenon of widespread existence and frequent association with conditions of accelerated soil erosion is attested by many published references. In a compilation of characteristics of navigable streams, the preliminary report of the Inland Waterways Commission in 1908 (*54*) stated concerning the Pearl River of Mississippi:

> Pearl River has completely changed its character in the last half century; from a slow, clear stream it has become a swift, muddy one, and from a good channel with a depth of five or six feet it is now shallow and much obstructed with drifts and logs. This rapid filling is due to the washing of the sandy uplands that have been opened up along the stream, with consequent choking of the river channel.

Concerning the Tallahatchie, another Mississippi river, Lowe (*37*) wrote:

> The Tallahatchie was formerly a navigable stream. Even as late as 1900 a small steamer drawing four feet of water plied on the Tallahatchie from Batesville downstream. Now the stream is choked with sand bars, and can be easily waded at almost any place * * *.

A condition common in the severely eroded area of silt loam upland soils derived from loess deposits, along the Missouri River in western Iowa, is cited by Towl (*53*) as follows:

> Silt deposits in ditches result in great damage to drainage districts and eventually affect railroads and other interests. For instance, in Fremont County, Iowa, the Burlington railroad raised its main line 7 feet at a cost of $36,000 to permit the construction of the Plum Creek floodway ditch to carry silt directly to the Missouri River. In Woodbury County, Iowa, the C. M. & St. P. Ry. has recently raised its bridge over the west fork of the Little Sioux River, and is planning other works, on account of drainage ditches which have been reduced in capacity by silt deposits.

Throughout the agricultural sections of the country it is common for railroads to raise tracks and move bridges on smaller streams and watersheds because of progressive building up of channels and valleys with erosional debris. A. W. Newton, formerly chief engineer for the Chicago, Burlington, and Quincy Railroad, states that

> prevention of soil erosion extends further than protection of soil—it prevents damage to adjacent property, caused by silting of stream channels and consequent overflow of valuable and productive farm lands in the valleys into which streams discharge.

He cites instances in which bridges on the Burlington route have had to be raised or relocated because of progressive building up of stream channels through sedimentation. At Lost Creek in southeastern Iowa it was necessary for the Burlington road to raise its grade and relocate a bridge, owing to formation of a large debris cone between the railroad embankment and the bluffs.

Meeker, in discussing a paper on the silting of the lake at Austin, Tex., states (*49*).

> Rising river beds of the Rio Grande near San Marcial, N. Mex., and the Arkansas in western Kansas, are also indicative of the heavy sand and silt burden resulting from erosion induced by settlement. The former has risen 12 feet and the latter 5 feet in a period of 45 years.

Damage to Flood-Plain Soils and Improvements

Damage by sediment deposition on soils and improvements along the flood plains of major streams and their tributaries is an important problem (fig. 19). Thousands of acres of productive valley lands are annually covered with deposits of coarse textured. infertile or sterile material.

In parts of the headwater section of the Yazoo Basin of northern Mississippi, sand deposition in minor valleys as a result of accelerated soil erosion was described as a seriously harmful process by Hilgard (*31*) as early as 1860, only about 20 years after the area was settled. Soil Conservation Service investigations in this same area during 1935 and 1936 delineated the areas of severe damage to bottom lands.

In Tobitubby and Hurricane Valleys, typical headwater tributaries in the most severely eroded part of the Holly Springs outcrop area, surveys show that some 14,000 acre-feet of sediment have accumulated during the past 75 years, everywhere burying the dark silt soils which covered the first bottoms under primeval conditions. This is equivalent to a surface layer 3 inches thick from the entire upland part of the watershed, yet represents only that fraction of the eroded material which has reached the valley bottoms, but failed

to be transported more than 20 miles, at the most, from the place of origin. It is especially significant that most of the sand has accumulated in the upper few miles of the valleys, where damage by sand overwash upon the bottom-land fields is very common, the deposits reaching thicknesses of as much as 10 feet upon parts of the flood plain. Such areas are now practically worthless for agricultural use, being given over mostly to briars and brush, or to swamp in places where the channel has been filled and drainage thus obstructed.

A total of some 4,500 acres in these two valleys has been covered by sand and silt deposits to depths of over 1 foot since the beginning of cultivation in the watersheds, the average depth of deposit being about 3½ feet. Only about 25 percent of the first bottoms are still worth cultivating, although at least an additional 25 percent would be suitable for agricultural use so far as character of the deposits is concerned, were it not for the frequent and often prolonged periods

FIGURE 19.—This field in a formerly productive valley in southeastern Minnesota was destroyed by deposition of sand washed from adjoining ridge farms.

of overbank flooding. The excessive flooding is due in part to the reduced capacity of the stream channel and drainage ditches in which much sand has accumulated. Serious damage to the bottom-land soils by sand overwash is, so far, chiefly confined to the upper few miles of the valleys, but the sand deposits here are unstable and potentially subject to intermittent transportation on down the valley.

In the southeastern Piedmont, especially through the Carolinas and Georgia, accelerated sedimentation not only has reduced the capacity of the stream channels and thus caused increasingly more frequent flooding of the bottom lands, but a large part of the first bottoms which had fertile silt loam soils when they were first cleared and cultivated have now been covered with infertile sand or even coarse gravel and boulders. This condition is recorded in numerous county reports of the Bureau of Chemistry and Soils (*28*), from one of which the following typical description is taken:

> Some of the areas mapped as meadow were originally good areas of Congaree silt loam or Congaree fine sandy loam over which a mixed covering of sandy material has been deposited following the clearing of adjacent hillsides. The

bottom land of Mill Shoal Creek about a mile from the county line is typical of this condition. It was reported that all the bottom was cultivated and the soil was Congaree fine sandy loam 12 years ago. At present the bottom land is a sandy wash with poor drainage and is covered with alders and willows * * *.

The extent of damage to the soil in cases of such sand overwash is indicated by comparison of two samples from a test pit in the flood plain of Eighteen-Mile Creek, Anderson County, S. C. A composite sample from the upper 2 feet of the present flood-plain deposit has been analyzed and also another sample from a depth of about 7½ feet, which was considered to have been the surface layer of the alluvial soil prior to accelerated erosion and sedimentation in the area. The results of these analyses are summarized in table 20, and show clearly the vastly inferior character of the present surface material.

TABLE 20.—*Chemical and mechanical composition of present and former alluvium, Eighteen-Mile Creek, Anderson County, S. C.*

Components	Present surface material depth 0–24 inches	Old soil depth 90–93 inches
Chemical analysis:	*Percent*	*Percent*
Nitrogen	0.007	0.09
Organic matter	.10	2.98
Potash	2.41	2.44
Phosphoric acid	.01	.16
Lime	.16	.31
Moisture at 105° C	.10	1.47
Mechanical analysis:		
Fine gravel	4.5	.0
Coarse sand	64.5	.4
Medium sand	24.0	.4
Fine sand	4.4	3.8
Very fine sand	.5	12.5
Silt	.0	39.8
Clay	2.0	40.3
	99.9	97.2
Colloid included in clay	1.0	32.5
Organic matter by H^2O^2	.0	2.3
Mineral matter dissolved by H^2O^2	.1	.5

In and adjacent to the Driftless Area of the upper Mississippi Valley—comprising large parts of southwestern Wisconsin and southeastern Minnesota and smaller adjacent sections in Iowa and Illinois—damage by sedimentation on valley lands often takes the form of accumulation of alluvial fans at the mouths of gullies and tributary valleys, where these debouch upon larger valleys of lesser gradient. On the basis of reconnaissance examinations made in 1937, it is estimated that over 1,000 acres of bottom land in the watershed of the Zumbro River, southeastern Minnesota, have been covered with alluvial-fan deposits to such depths as to permanently reduce the productive capacity of the land an average of 80 percent, and that an additional 200 acres was suffering similar damage annually, about one-quarter of which will be permanent damage. In one instance, as a result of a single storm which produced excessive erosion in a tributary of the Zumbro, an area of 600 acres in the Zumbro valley was covered with sand and silt to depths up to 5 feet, according to a survey made at the time.

The damage by growth of alluvial fans is not confined to the land, but frequently necessitates considerable repair and maintenance work on the highways. In Winona County, Minn., for example, the county engineer has estimated the average cost of removing sediment from the county and township highways at approximately $30,000 annually.

It is also known that in some parts of the Texas Coastal Plain valley bottoms have been completely covered with sandy sediment. In places, as in the valley of Big Sandy Creek in Wise County, the new deposits reach a thickness of as much as 6 feet above the old silt soil, and the former valley fields have been abandoned to a growth of willows and valueless brush, and now afford only poor pasture.

Following the greatest flood of record in the Ohio Valley—that of January 1937—the Soil Conservation Service made a survey of the Ohio Valley between Pittsburgh, Pa. and Cairo, Ill. to estimate the amount of sediment laid down by floodwaters as well as the amount of soil material removed by scour or flood erosion from valley agricultural lands.

The results of this survey indicate that in the Ohio Valley about 812,000 acres including urban areas amounting to 91,000 acres were flooded. Out of this total 313,000 acres showed no measurable effects from either sedimentation or scour. The area on which silt, silty clay, and loam deposits were laid down amounted to 320,000 acres and the area covered by medium-sand deposits amounted to 22,000 acres. The area affected by removal of soil amounted to 70,000 acres. The field evidence indicated that there was very little permanent damage to valley lands affected by deposition of silt, silty clay, and loam deposits, but where more than 3 inches of medium sand has been laid down definite impairment of the productivity of the land might be expected. The area covered by more than 3 inches of medium sand was 5,700 acres.

RUN-OFF AND EROSION CONTROL BY CROPPING PRACTICES AND MECHANICAL MEASURES

All watersheds cannot be retired entirely to grass and forest cover. Approximately 350,000,000 acres of cropland are needed to produce the food and fiber required by the nation's population. Of this acreage it is estimated that all but approximately 75,000,000 acres stands in need of specific water and soil-conservation practices if agricultural production is to be sustained. It is therefore important to take measures to reduce to a minimum soil and water losses from these agricultural land without reducing their value as producing units.

Certain cropping practices and other measures largely of a mechanical nature reduce soil and water losses from croplands and other areas lacking adequate protective cover. The use of these practices and measures as control permits the safe use of a larger percentage of farm land for crop production than otherwise would be possible.

In this connection it should be clearly understood that the application of a soil and water conservation program on a given farm or unit of land is not limited to the selection of the one method of treatment which would appear to be most effective. Rather, all practical

methods of control must be used in accordance with the needs and adaptability of the land. Although in the next few pages special conservation practices applicable to farm lands are discussed separately, in application these must be used in combinations that will mold into a well-knit conservation and land-use plan.

Crop Rotations, Green Manure, and Winter Cover Crops

Many of the advantageous effects of vegetative cover described in previous sections of this report may be obtained for cropland by proper planning and use of crop rotations, green-manure crops, winter cover crops, and by applying barnyard manures. These practices may be made even more effective by combining them with other practices such as contour strip cropping and terracing.

The effectiveness of close-growing vegetation in a crop rotation system in checking run-off and erosion is illustrated in Figure 20. The data here presented are given in terms of yearly averages. However, the trend for the year follows that of individual rains. The reduction in soil and water losses for the areas in rotation compared to those in continuous intertilled crops is due both to the cover provided during certain years of the rotation period and to the additional organic matter added to the soil by the close-growing crop in the rotation. Almost invariably reduced water and soil losses occur from intertilled cropland following a close-growing crop when compared to losses from land in the same intertilled crop grown continuously.

The growing of winter cover crops and green-manure crops contributes to soil and water conservation in the same manner as good crop rotations. They protect the land during their growing period and add to the organic content of the soil when plowed under. Barnyard manure stimulates absorption of water both by increasing the organic matter content of the soil and by promoting a more vigorous vegetative growth. Commercial fertilizers and agricultural lime may contribute by improving vegetation. It is highly essential that crop rotations which include the maximum use of close-growing crops, supplemented with green manure and winter cover crops, be a part of any soil and water conservation program for croplands.

Strip Cropping

Strip cropping is a special adaptation of control by vegetal means. Strips of close-growing crops placed on the contour are alternated with strips of clean-tilled crops. This has proved an effective measure for reducing soil losses and water run-off on agricultural lands. The width of the strips depends on the steepness and length of the slope, soil characteristics, and crops to be grown. On steeper slopes the strips are narrower and the proportion of sod-forming strips is greater.

A strip-cropping system provides the advantages of a rotation (fig. 21). At the same time the protective strip retards the movement of water from the slope, usually causing more of it to be absorbed and materially lessening soil losses. Strip cropping has been introduced widely in recent years throughout the agricultural

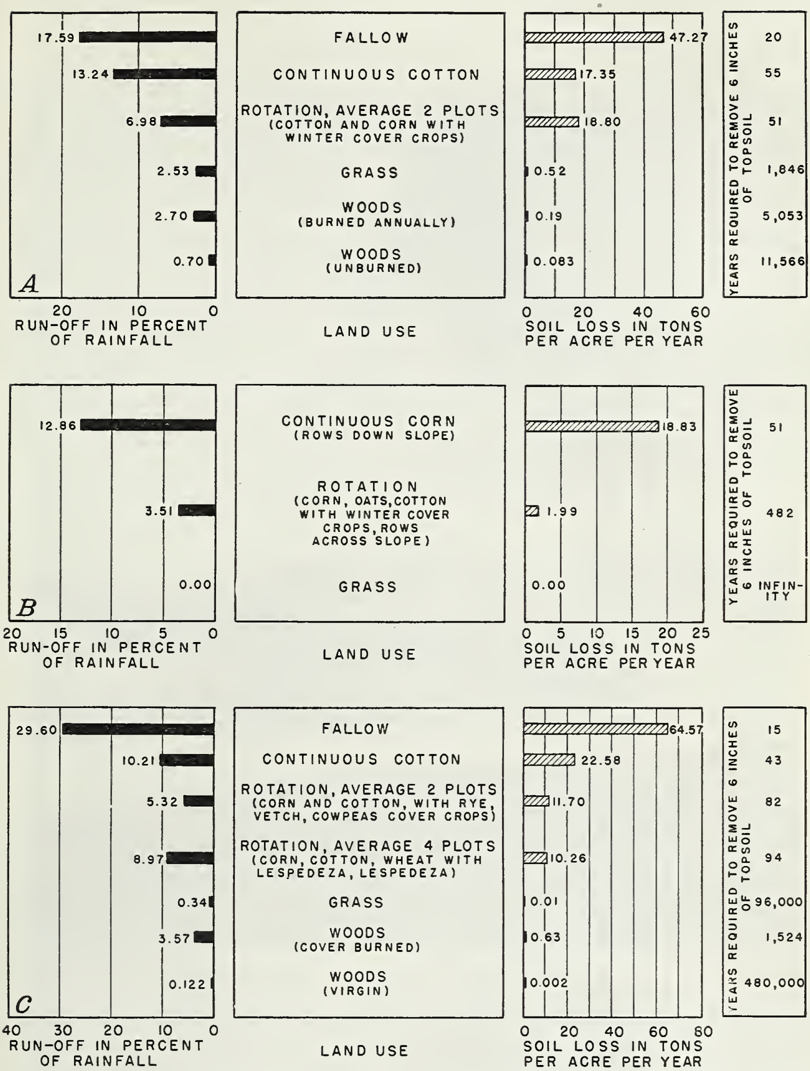

FIGURE 20.—Effect of crop rotation in retarding run-off and soil erosion under various conditions: *A*, Statesville, N. C., Cecil sandy clay loam, 10-percent slope, average annual rainfall of 45.22 inches, 5-year period 1931–35; *B*, Temple, Tex., Houston black clay, 4-percent slope, average annual rainfall of 27.51 inches, 4-year period 1931-34; *C*, Tyler, Tex., Kirvin fine sandy loam, 8¾-percent slope, average annual rainfall of 40.52 inches, 4-year period 1931–34.

sections of the country by the Soil Conservation Service. Farmers readily have accepted it as a water and soil conservation practice. They see definite proof of its value. However, little quantitative data are available concerning run-off retardation afforded by this practice. As an example of the effectiveness of this practice, the results obtained at Temple, Tex., are shown in table 21.

TABLE 21.—*Water and soil losses under different cropping methods, Houston black clay, Temple, Tex.*

Cropping practices	Area	Annual losses		Rain of May 18, 1935: 3.45 inches		Rain of July 27, 1935: 2.3 inches	
		Water of precipitation lost	Soil lost per acre	Water of precipitation lost	Soil lost per acre	Water of precipitation lost	Soil lost per acre
	Acres	*Percent*	*Tons*	*Percent*	*Tons*	*Percent*	*Tons*
Cotton, with strip cropping [1]	1.38	9	5.2	37.4	0.98	33	0.02
Cotton, rows on contour [1]	1.39	19.6	52.3	57.6	17.2	64.2	12.50
Corn, with strip cropping [2]	.09	.95	.3				
Cotton, rows, down slope [2]	.03	14.46	15.61				
Cotton, rows on contour [2]	.05	5.8	5.52				

[1] Data for period July 30, 1933 to Dec. 31,1935; slope 4 to 6 percent.
[2] Data for period 1932 to 1935, incl7sive; slope 4 percent.

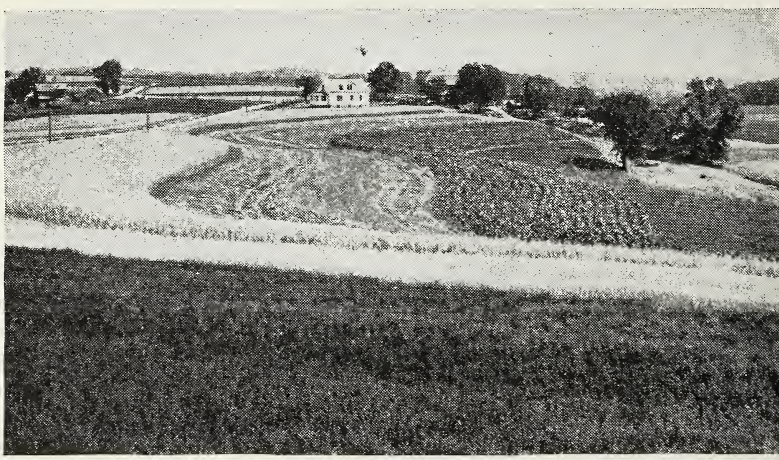

FIGURE 21.—A strip-cropping system provides the advantages of crop rotation while at the same time retarding the movement of water down a slope.

TERRACING

Terracing of both crop and pasture lands has an important place, under certain conditions, in the upstream control of storm run-off. In the more humid sections of the country, where it is necessary to lay out terraces on a slight grade in order to allow surplus water to drain, terraces are not so effective for conserving water as they are in drier agricultural regions, where they are laid out on the exact contour and all of the water is held in the field. Figures 22 and 23 show the degree of control achieved on cultivated land by terraces. It should be noted that, although this mechanical type of control

markedly reduces both run-off and erosion, it does not achieve as marked a reduction of these losses as do such vegetative treatments as reforestation and the planting of slopes to grass. Yet it is still highly important for it cannot be expected that vegetal controls can

FIGURE 22.—Cultivating on the contour rather than with the slope, supplemented by strip cropping or terracing, would have largely eliminated the soil losses shown here. Farming down the slope forms channels which are conducive to rapid run-off and acceleration of erosion.

be extended to all lands and still provide for the Nation's agricultural needs.

The branch of the Oklahoma Agricultural Experiment Station at Goodwell, Okla. (*9*), demonstrated that the average soil-moisture con-

FIGURE 23.—Property constructed terraces are effective in conserving water.

tent was increased approximately 25 percent by level terracing and contour tillage. At Goodwell the additional moisture conserved in this way resulted in seven better-than-average yields of wheat during a 10-year period whereas without contour tillage or terracing

only four crops of better-than-average yield were produced over the same period. The reduction of run-off through terracing and contour tillage increased the chances for a successful crop by approximately 75 percent, with a corresponding increase in yield of 35 percent. Bennett further reports that an average of 1 inch of rainfall was stored above normal during the spring of 1936 over 2,474,000 acres of contour-listed land in the southern plains region of Colorado, New Mexico, Kansas, and Oklahoma. On the Soil Conservation Service watershed project at Vega, Tex., 10 days of rain totaling 5.48 inches penetrated the soil to an average depth of 2.15 feet on contour-tilled land. In similar fields farmed in straight rows, moisture from the same rain period penetrated to an average depth of only 1.48 feet (*56*).

At Spur, Tex., in 1935, the total rainfall for the month of May was 4.54 inches and for June 6.93 inches, the rainfall for the two months amounting to half the precipitation for the year. At the Spur Experiment Station run-off results were obtained from nine 10-acre fields of cotton all on a slope of approximately 0.5 percent. Three of these fields had the rows running with the slope, three with rows on the contour, and three with contour rows and level closed-end terraces. The measured run-off for the different treatments, during May and June, and yield of lint cotton are tabulated below:

Kind of rows	*Average run-off of three 10-acre areas (acre-inches)*	*Yield of Lint cotton (pounds per acre)*
Running with slope	3.0	104
Contoured	.5	199
Contoured and land level terraced	.0	219

These data are indicative of the high run-off that may occur from these cultivated soils on practically level land unless water-conservation practices are applied. They also show the effect of conserving water on the yield of crops. Although the terraces and contour rows conserved extra water during every run-off-producing rain during the remaining portions of the year, much of the increased yield can be attributed to the additional water conserved during May and June.

In September 1936, two record-breaking rains occurred in the Concho River drainage area of Texas. The rains were separated by an interval of 1 day. A total of from 15 to 20 inches of rain was recorded for the 3-day period on numerous gages scattered through the drainage area. Soil and water conservation operations of the Soil Conservation Service, including level terracing and vegetative treatments, received a supreme test. Surveys made following the storm indicate remarkable reductions of water run-off and soil losses on treated lands. Contour ridges in pastures suffered no damage except in a few small areas where flooded streams got out of banks.

The intense storms sent the Colorado River on a rampage, causing severe flood damage to lands below the Concho drainage area. It is estimated by field specialists, however, that the level terraces alone held back more than 8,000 acre-feet of water which would otherwise have drained into the Concho.

The heavy rainstorms of the summer of 1936 in northern Utah provided some excellent opportunities for observing the effectiveness of the terrace-trench system of flood and erosion control as developed for steep depleted range lands on the Davis County watershed (*3*, *5*).

On two occasions very serious mudflows occurred on four unterraced tributaries of Farmington Canyon, whereas the terraced headwaters of Steed, Ford, Barnard, and Davis Creeks immediately adjacent to Farmington Canyon provided adequate protection against flash run-off and floods. Rainfall was practically the same on all areas as shown by series of 62 standard and 2 intensity rain gages on these watersheds.

On July 10 a rainstorm of 1.15 inches occurred on a 150-acre watershed tributary to Parrish Creek, of which 0.95 inch fell the first 15 minutes of the storm. As a result of this intense storm, stream flow increased 160 times over normal, or from 0.10 to 16 cubic feet per second for a period of 20 minutes immediately after the storm. Observations and measurements revealed that all of the run-off which contributed to the flash flow of the stream came from about 5 percent or 7.5 acres of the watershed, principally from cleared areas surrounding buildings and from roads. No surface run-off was contributed from about 45 percent of the area on which there was a dense stand of vegetation, nor was any run-off contributed directly from the remaining 50 percent of the watershed controlled by the terrace-trench system.

On the 75 acres of controlled watershed area, however, water accumulated in trenches in an amount that indicated surface run-off was proportionately as great between the terraces as on the roads and clearings around the buildings. Thus it is believed that the discharge from this tributary probably would have been 10 times greater, and undoubtedly would have caused serious damage in the valley below, had it not been for the terrace-trenches which held back this surplus water.

Contour Furrowing and Listing

Another effective water-conservation measure used widely by the Soil Conservation Service is the practice of contour furrowing pasture and grazing land and contour listing cultivated land. This practice is meeting with favor among farmers generally. Contour furrowing of pastures is a simple process, consisting of plowing contour or level furrows, usually from 8 to 15 feet apart. On land being prepared for seeding to pastures contour furrows may be spaced as closely as corn rows. Preliminary studies at Zanesville, Ohio, with 437 soil samples taken in the middle of October 1936, from both contour-furrowed and unfurrowed pastures show that the furrowed pastures contained an average of 29.5 percent more soil moisture than did the unfurrowed pastures.

A striking example of the effect of contour furrowing on water-flow retardation has resulted from the extensive use of this practice on the Baker Creek watershed in Claiborne County, Miss. A considerable portion of the upper reaches of this watershed have been furrowed. Since this treatment overflow of Baker Creek, 2½ miles from the headwaters, has not occurred. Comparable Willis Creek, with the same rainfall over its watershed, has continued to overflow 6 to 12 times a year.

Contour listing is proving highly beneficial as a water-conservation measure throughout the Great Plains region and in those portions of the Corn Belt where the lister is commonly used. At the Hays,

Kans., experiment station, land listed up and down the slope yielded over a 2-year period (1934–35) an average of 20.66 percent run-off compared to 3.04 percent run-off for contour-listed land.

The basin lister, an implement which leaves dams in the furrow at regular intervals, has proved very effective at Hays. A study of dam listing has been carried on for several years. By its use run-off losses during heavy rains have been reduced to zero as compared to water losses of 50 percent and more from adjacent untreated areas.

In February 1937 the city of Freeport, Ill., experienced a severe flood. On the watershed of the Pecatonica River which runs through Freeport, the Soil Conservation Service had listed a few fields. After the storm giving rise to the flood no run-off occurred from areas treated with the basin lister, while adjoining untreated land yielded a high percentage of run-off.

Figure 24.—Water-conservation reservoirs have an important place in headwater treatment and provide needed water supplies

Structures

In this bulletin, a brief discussion of structures will suffice, but it should not be inferred that this phase of headwater treatment is relatively unimportant. On the contrary, such installations as the "drop inlet soil-saving dam," "check dams," "head flume," "head spillway," "rock-notch spillway," "masonry arch dam," "earth dams," timber "crib dams," "diversion ditches," "water-spreading works," and innumerable other forms of small dams (fig. 24) and devices constructed of temporary or permanent material, occupy a most important place in upstream work from the standpoint of both water and soil conservation. These various structures are now being widely used by the Soil Conservation Service, the Forest Service, and other governmental agencies engaged in water- and soil-conservation activities.

In the more humid parts of the country such structures have been used thus far largely to stabilize gullies and prevent their further encroachment upon and destruction of otherwise valuable land. Throughout the more arid sections of the country, and in some parts of the humid region, they are built primarily to conserve for livestock water which otherwise would be wasted.

Such structures contribute to the control of storm flows. They have further value in catching silt, stabilizing drainage channels, and preventing additional erosion within the drainage channel itself.

CURRENT RESEARCH IN WATER CONSERVATION

Research in forestry and agriculture has long been a major activity of the Department of Agriculture. Research into the influence of forests and other vegetal cover on floods and related phenomena, and research into the effect of land use, farming practices and erosion-control measures on soil and water conservation, however, has not been under way as long or on as comparable a scale as in other fields. The first specific investigations of the influence of vegetation on stream flow were begun in the Forest Service as early as 1906. Prior to 1930 investigations were carried on by several bureaus, some independently, others in cooperation with States and other agencies. By far the greater part of the work, however, was not designed to answer questions about water conservation directly, but attacked the problem by indirect means. These investigations served, however, to develop a framework around which the more recent research has been built. And many of these early studies having slight apparent relation to the water-conservation problem yielded highly significant results. It may be helpful to give a brief description of such work prior to about 1930.

An early study on forest land was that at Wagon Wheel Gap, Colo., started late in 1910. In this study an effort was made to determine the influence of forests on stream flow by comparing the run-off from a forested watershed with that from one on which the forest was cut. This study, and somewhat similar but more generalized stream-flow studies in southern California, shed more light on the effect of cover on erosion than on run-off, but they did furnish some new concepts of forest relationships. Another long-time experiment was started in Utah in 1914 to determine the effect of range cover and grazing on stream flow and erosion. Various other investigations were made in a number of different localities of the effect of forest on snow and on climate.

Studies in 1917 and 1918 on the Murchison farm, 4½ miles southeast of Jackson, Tenn., produced early information on rates and amounts of run-off from agricultural areas. The six watersheds ranged from 1¼ acres to 112 acres and the data obtained were widely applied to the design of drainageways, terraces, storm sewers, culverts, and other hydraulic structures on agricultural areas. These studies emphasized the need for detailed hydrologic data in other physiographic and climatic provinces.

The Soil Survey, which is carried on in cooperation with many States, furnished comprehensive knowledge of the relation of erosion problems to agricultural practice and soil types. Laboratory investigations of the physical and chemical composition of soils supplied information on absorption and water-holding capacities of soils and effects of humus.

Other early work dealt with the water requirements of plants and the duty of water for irrigation crops. These studies, of which there were a number in different parts of the West particularly, supplied the first authentic information on transpiration by plants in America.

Other investigations related to evaporation and the rate of water infiltration into the soil. Studies of drainage gave information on water movement through soils. Studies were also begun in this period to determine the possibility of making snow surveys in order to forecast water yields. The Weather Bureau carried on studies of precipitation and floods. These were of inestimable value in flood-forecasting work.

In 1928, Congress passed the McSweeney-McNary Forest Research Act which authorized a comprehensive program in forest research including that of methods of "obtaining favorable conditions of water flow and the prevention of erosion." In 1930 an item providing specifically for "soil erosion investigations" was included in the Agricultural Appropriation Act. The funds available were divided among three bureaus. The Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering devoted their attention to investigations of agricultural land problems, the Forest Service devoted its attention to problems of forest and range land.

In 1933 the passage of the Emergency Conservation Work Act creating the C. C. C. aroused further interest in forestry and soil and water conservation. With the passage of the National Industrial Recovery Act and the Tennessee Valley Authority Act, funds were made available for various activities, including action programs in soil and water conservation. These national enterprises led to an increased demand for research results. Consequently, emergency funds in considerable amounts were made available for initiating various studies. The need grew greater as conservation programs got under way, and as drought and dust storms in the Middle West and floods in the East and far West emphasized the need for a comprehensive attack on the water problem.

The work which bears upon water and soil conservation is distributed among several bureaus of the Department. Two bureaus are now engaged in a direct attack on the problem: The Soil Conservation Service and the Forest Service. The research of the former agency is directed primarily toward solution of agricultural land problems, the latter to solution of forest and range problems.

Experiment Station Investigations on Agricultural Land

Since 1930 the Department of Agriculture has established 19 soil conservation experiment stations, where soil and water losses under various soil, slope, and crop conditions have been quantitatively measured on agricultural land. Ten of the stations have been in operation 6 to 9 years. These stations (fig. 25) have provided the essential facts which have made known to the nation the seriousness of soil wastage. They have shown the interrelation between the loss of soil and run-off.

These experiment stations study the intensity, duration, and seasonal occurrence of rains in their relation to soil erodibility, slope, crop cover, and land use. The losses of water and soil which occur, the relative value of various crops in preventing such losses, and the effect of terraces on run-off have been studied. The role close-growing vegetation plays in preventing rapid run-off and in reducing soil loss has been clearly shown.

Various soils react differently to treatment measures and show varying capacities for absorbing water. Some soils may have twice the absorptive capacity of others. Knowledge of such soil characteristics is being extended. It is becoming one of the important bases of soil management for the control of soil and water losses. Tillage and cultivation practices and soil treatment suitable to each soil series are being sought in order to reduce the losses of fertile soil, retain water for plant growth, and increase the ground-water supply.

Cropping systems are being developed which retain the basic farm practices of each region, while maintaining or raising the level of farm income and insuring improvement in practical methods for ameliorating soil and water losses. It has been shown conclusively that erosion control measures that are quite satisfactory with some soil types under certain conditions may not be suitable for other types or under different conditions. Measures to prevent soil and water losses must be varied from one area to another to fit changing farming practices, rainfall, soils, and slopes.

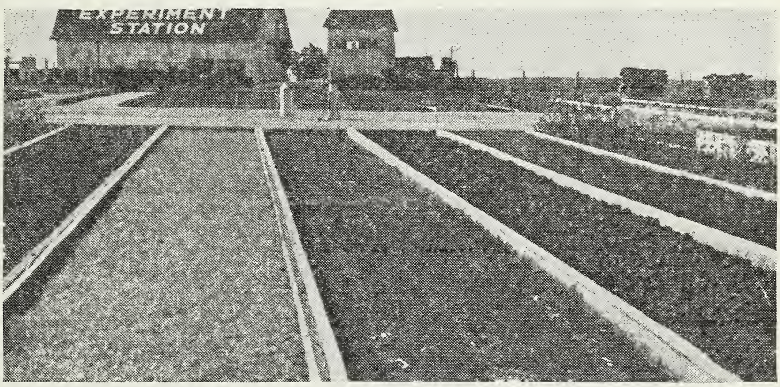

FIGURE 25.—Run-off plots at the Blacklands Experiment Station in Texas.

The locations and names of the soil conservation experiment stations are as follows:

Name	*Location*
Red Plains	Guthrie, Okla.
Blacklands	Temple, Tex.
Central Kansas	Hays, Kans.
Sandy Lands	Tyler, Tex.
Northern Missouri	Bethany, Mo.
Central Piedmont	Statesville, N. C.
Pacific Northwest	Pullman, Wash.
Missouri Valley Loessial	Clarinda, Iowa
Upper Mississippi Valley	La Crosse, Wis.
Northwest Appalachian	Zanesville, Ohio
Northeastern Limestone Valleys	State College, Pa.
Southern New York	Ithaca, N. Y.
Southern Great Plains	Amarillo, Tex.
Northeastern Pasture Lands	Beemerville, N. J.
Southern Piedmont	Watkinsville, Ga.
Southern Illinois	Dixon Springs, Ill.
Central New York	Marcellus, N. Y.
Claypan	Fulton, Mo.
Northeastern Coastal Plains	Marlboro, N. J.

Experimental Watershed Studies in Agricultural Areas

Although plot work is invaluable in making studies of isolated factors, results from plots must be complemented by watershed studies in order to establish an understanding of the complex relationships existing between the various factors influencing run-off and flood flows on natural watersheds. Therefore some studies must be made on a watershed basis.

The objectives of these experimental watershed studies are: (1) To determine the effect of erosion-control practices and land use upon the conservation of soil and water for agricultural and domestic purposes, (2) to determine the effect of erosion-control practices and land use upon stream flow, and (3) to determine the rates and amounts of run-off and eroded soil material from rains of different amounts and intensities, for use in the economic design of erosion and water-control structures.

These studies are conducted on watersheds ranging in size from 5 to 5,000 acres. Detailed investigations are being made of the action of water from the time it reaches the ground as precipitation until it leaves the watersheds as surface or underground flow, including studies of precipitation, percolation, evaporation, transpiration, and ground-water movement.

While it is generally known that the rates of run-off and erosion per unit of area from watersheds decrease as the size of the watershed increases, very little substantiating data have been collected. In order to determine these variations in rates and amounts of run-off accurately, run-off data must be collected from watersheds of various sizes and characteristics and a detailed study must be made of rainfall distribution and frequency of rains of different amounts and intensities and the contribution of floodwaters from small areas toward the development of flood hydrographs on large watersheds.

The variations in climatic and other factors affecting run-off and flood flow will require the establishment of watershed projects in all of the more important regions in order to obtain information for use throughout the entire country. Information of this nature is needed for planning all water-control projects. Correct design of erosion-control and flood-control structures depends on it. With such information at hand, structural failures will be reduced or prevented, and costs will be reduced because large factors of safety in design can be obviated.

The first experimental watershed project was established for the North Appalachian Region near Coshocton, Ohio, in the Muskingum Watershed Conservancy District. Intensive studies are being made of the effects of land use and erosion-control practices on the conservation of soil and moisture and on flood flows on 44 whole watersheds supporting various cover types ranging from 3 to 4,600 acres.

There are also seven run-off measuring stations ranging from 3,500 to 31,300 acres in the Mill Creek Basin, of which Little Mill Creek is a part. Records taken at these stations will permit the study of development of floods on watersheds up to 50 square miles for the purpose of widespread application of the intensive data obtained on the small experimental watersheds. Likewise, the Department's research activities in cooperation with the Munkingum Watershed

Conservancy District will provide for the application of these data to watersheds of about 8,000 square miles.

A similar experimental watershed project for the Blacklands region has been established on the Brazos Drainage Basin near Waco, Tex., where erosion, hydrologic, land use, and soil data are being observed on 30 watersheds ranging from about 3 to 6,000 acres. A third experimental watershed has been established for the Central Great Plains region in the Republican Drainage Basin near Hastings, Nebr. Hydrologic, land use, and soils data are being intensively observed on 22 watersheds ranging in size from about 3 to 3,500 acres. Eight plots of 0.7 acre each have been established to study the effect of controlled and uncontrolled grazing on the conservation of soil and moisture.

Eighty-two small experimental watersheds have been established on 19 demonstration projects, giving a wider geographical distribution to the rainfall and run-off studies.

Research in Forest and Range Influences

The McSweeney-McNary Forest Research Act of May 22, 1928, and as amended January 15, 1936, provided for a net of regional forest experiment stations, one for each section of the country in which forest and range problems were important. All but one of these stations for the continental United States, that for the Great Plains region, have been established. At each of these stations work bearing upon the problem of water and soil conservation is under way to a greater or lesser extent. At some of them, work in "forest and range influences" is a major activity. Although station headquarters have been established at some convenient point, usually in cooperation with some university, the active field work is under way at one or more experimental forests or ranges. These are usually established on public lands. Other work occasionally is done on private lands under agreement with the owner. Many of the investigations are carried on cooperatively with Federal or State agencies.

Investigations in forest and range influences take a variety of forms depending upon the intensity with which the individual project is conducted. In general, the program in this field is to determine the effect of forest, brush, and range cover and its treatment on water, soil, and climate. It is to determine the extent such natural cover may serve as a factor in providing satisfactory conditions of water flow on entire watersheds or parts of them, and if so whether and how such cover can be utilized for man's use or benefit. It seeks to ascertain under what conditions of precipitation, topography, and soil, the character and condition of the cover exert their influences. It endeavors to ascertain how and under what circumstances, the cover will conserve water supplies and deliver to the streams the maximum amounts of usable water. It attempts to develop practical measures applicable to wild lands, that flood flows may be diminished, that surface run-off and erosion may be controlled, that water can be absorbed by the soil, and that stream flow can be regularized. In short, it is designed to develop facts and remedial measures in water control for wild lands as a basis for action programs by Federal, State, and private agencies interested in such lands.

The approach taken to the problem of water control is that of breaking it down into parts, studying each of these parts separately, and analyzing the results of each in relation to the others.

The investigations included in the program necessarily cover a wide field of biological, physical, and engineering factors. On experimental watersheds, it is planned to manipulate the cover to determine the effect upon water yield and water behavior. This study is also extended to the streams of larger watersheds, composed of aggregates of smaller areas, in order that gross effects can be observed closely. Here again, when sufficient data are available, it is planned to manipulate, to modify, or alter cover conditions to various degrees and by various methods, so that the relations between cover and water yield and associated phenomena may be determined. These studies are further amplified by studies of devices to be used in connection with the natural cover.

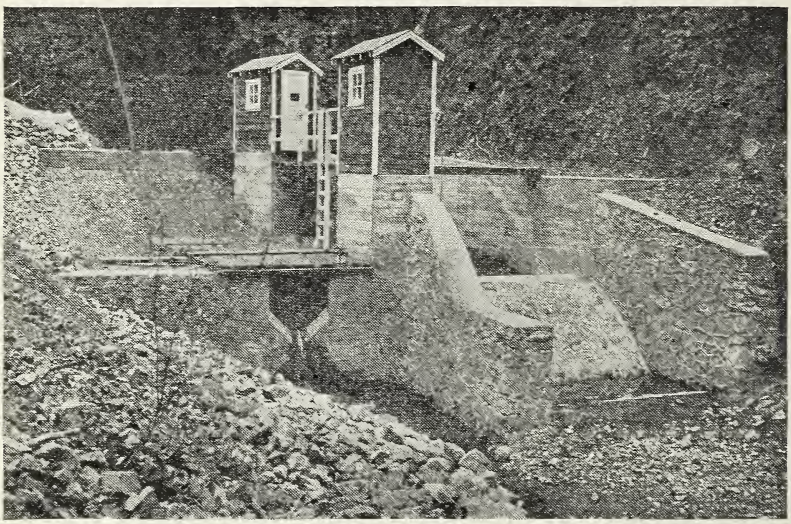

FIGURE 26.—Stream-gaging station at San Dimas Experimental Forest in southern California

It is obvious that such a series to be complete for any one given set of conditions requires not only considerable time, but involves heavy installation costs. Thus at the San Dimas Experimental Forest (fig. 26) in southern California the total expenditures for the project to date approximate $1,500,000 including the cost of such related items as roads, firebreaks, laboratories, etc. This does not include the cost of the larger dams erected by Los Angeles County for flood control but does include the expenditures of all cooperating agencies, of which there is a considerable number. At the Coweeta Experimental Forest in North Carolina, where accessibility is greater and areas required are smaller in size, expenditures have been much less. Here the completed installation probably will not cost in excess of $300,000. Obviously, work on such an intensive scale cannot be carried on without large expenditures for labor in constructing dams, excavating, and developing reservoirs, and installing weirs and gaging stations.

The program for forest lands calls for 25 major projects of the San Dimas types, but all on a much smaller scale, for the major natural cover types, and for an equal number of minor studies of types of less importance.

Economic Research in Soil Conservation

Economic research in soil conservation is planned to evaluate the current soil-conservation programs in order to develop an economic appraisal of their effectiveness, and in order to develop suggestions for their improvement.

In order to accomplish the above objectives, the results thus far achieved as a consequence of the soil-conservation programs are appraised. These results can be used as an indication of performance and as a basis for computations of probable results as the soil-conservation programs are enlarged.

Such studies yield information as to the effect of a soil-conserving system of farming in preventing damages to roads, to streams, to reservoirs, and to bottom lands as a result of siltation and of eliminating the costly public expenditures for clearing roads, dredging streams and reservoirs, or replacing the latter.

Hill-Culture Research

Maintaining a good plant cover is the primary means of preventing and reducing soil erosion and keeping sediment out of surface waters. Steep slopes may be made safe against erosion by establishing inexpensively such covers as ordinary grasses, wild plants, and woods provide. However, the relatively low crop value of natural plant cover and the long time required by it to yield cash returns often discourages the planting of such vegetation. Hill culture consists of the systematic search for and adaptation of superior strains of erosion-resisting plants having an economic value. To meet outstanding needs with respect to hill-culture objectives, the Soil Conservation Service, the Bureau of Plant Industry, and the State agricultural experiment stations are seeking better erosion-control plants, endeavoring to work out their proper management, and developing better economic uses for the products.

Sedimentation Studies

It is recognized that accelerated soil erosion produces abnormal quantities of silt, sand, and gravel which are carried from fields and deposited at lower levels. The resulting accumulations of sediment cause impairment of drainage and the fertility of soils on the lower slopes of fields and on agricultural bottom lands; they cause abnormally rapid filling of stream channels and reservoirs, with consequent damage to water supply, water power, irrigation, drainage, navigation, and flood-control developments. Further comprehensive investigations of the entrainment, transportation, and deposition of erosional debris by flowing water, and the resulting damages are necessary in developing more effective soil-conservation methods and to aid in the establishment of a complete integration of land-use policies and soil-

and water-conservation practices. To meet this need a project of sedimentation studies was organized.

These investigations are designed to furnish: (1) Information on the damage done by sediment as well as the magnitude of potential damage to be expected if present practices are continued; (2) a measure of the relative needs of the different watersheds for erosion control and readjustments in land use from the standpoint of protecting developed water storage, flood-control improvements, and investments in agricultural land subject to damage from erosional debris; (3) further knowledge of the natural laws governing the erosion of soil by water; and (4) assistance in developing economical methods of preventing damage to valley agricultural lands and to many valuable downstream developments and resources.

These studies of the entrainment, transportation, and deposition of erosional debris by flowing water and the resulting damages are divided into the following four projects:

(1) Investigations through field studies and surveys of reservoir silting and its relation to the land use and topographic conditions within the watershed.

(2) Investigations of the sources, quantities, forms, and effects of recent accelerated sedimentation in stream channels and on valley lands throughout the country and development of new methods for reducing and eliminating damage of erosional debris through control of erosion and sedimentation within the valleys.

(3) Investigations at field stations of the total sediment loads carried by the streams, correlation of the different phases of these loads with hydraulic functions of the streams and the land use and topography of the watershed, establishment of empirical methods for the determination of the bed load of erosional debris carried by any stream, and studies of engineering methods for the control of its movement within a stream.

Climatic and Physiographic Research

The focusing of attention on run-off and stream-flow problems has demonstrated the need for the development of new modes of approach in the collection and analysis of climatic data. Since the amount and nature of stream and overland flow depend on the particular characteristics of the storms producing such discharge it has been necessary to obtain more detailed information regarding storm structure and rainstorm patterns. Such specific information was supplied by the microclimatic studies carried out in Oklahoma, and at present being pursued in even greater detail at the Muskingum Climatic Research Center.

These records from closely spaced stations have made it possible to develop principles regarding rainstorm morphology which provide the basis for relating erosion and run-off to the particular climatic factors which produced them. Further, studies conducted in the Muskingum Basin have indicated the feasibility of developing a climatic index of soil-moisture deficiency. Since crop growth is related not to total precipitation figures but rather to the water available in the soil, and since the amount of run-off from any storm is greatly influenced by the amount of infiltration which occurs, this index would serve a much-needed purpose. In order to construct such an index precipitation records must be examined, evapotranspiration rates must be carefully estimated, hydrographs must be subjected to analysis, and surveys must be made of surface-slope-soil conditions and of detailed land use from week to week through-

out the year. All of these approaches are being followed concurrently and in an integrated manner in the Muskingum Watershed. As a part of this work a method for determining the rate of evaporation not merely from free water surfaces but from land surfaces and vegetation as well, has been developed and is now undergoing tests in Ohio and Virginia. The approach which is being utilized rests on modern meteorologic theory and stresses turbulence as being a critical mechanism in the transfer of moisture from the ground surface aloft. The perfection of this method will obviate the necessity of relying on pan or atmometer measurements which are at best merely rough indices of evapo-transpiration and will provide investigators with data showing the real total moisture loss from land surfaces.

In addition, certain climatic elements such as precipitation intensity, storm duration, and drought frequency are receiving particular attention. Such factors are critically related to erosion and run-off. Any watershed treatment can be rationally instigated only if the climatic risk with respect to these elements is known. It is essential, therefore, that variations in these factors from season to season and area to area be determined, and that maps and figures be prepared showing the climatic hazard to which a watershed in any part of the country is apt to be subjected over any given period of years. Specific studies along this line of inquiry have already been made and are being extended to include all parts of the United States.

All of this climatic work rests upon physiographic studies carried out in the field. The climatic work is supplemental to the field work inasmuch as the physiographer requires climatic data and information in order to understand the erosion and run-off phenomena which he observes. The field work, on the other hand, is indispensable to the climatologist since his predicted results must constantly be checked against quantitative and qualitative reports as to rates of soil wastage, rates of water discharge, and the particular forms which erosion assumes. As part of this integrated climatic and physiographic work studies have been made of rate and mode of gullying, frost heaving, sheetwashing, and of surface-soil-slope relationships as they affect run-off and erosion.

Studies on Demonstration Projects

The Soil Conservation Service has established 175 demonstration areas in locations representing nearly all of the types of farming areas in the United States. All of these projects are equipped with rain gages. On many there are stream-gaging stations.

Erosion-control practices installed in these areas are thus being tested under actual use. Continuous observation of their performance, in comparison with observations made in adjacent areas, provides excellent opportunities for obtaining much information of value, particularly locally, on the influence of modified and unmodified land use on run-off and flood flows.

Short-time field tests will be made on many project areas and many detailed questions on land-water-plant relationships will be at least partially answered. Unanswered questions will be referred to the

soil conservation experiment stations and to other research stations for further study.

Irrigation Investigations

Studies designed to show the amount of water utilized by irrigated crop plants were started by the Division of Irrigation Investigations of the Bureau of Agricultural Engineering. This Division is continuing these studies under the Soil Conservation Service to which it was transferred on July 1, 1939. This Division also investigates water consumption by riparian vegetation, such as marsh grass, tules, willows, etc., which make heavy drains upon irrigation water in ditches and along water courses. Most of these studies are being done in California and Oregon. Drainage investigations in relation to alkali also contribute to our knowledge of soil and water conservation. Measurements of the silt load of streams are being made, chiefly in Texas. In many places in the West, the problem of safeguarding agricultural lands from deposition of solids carried in minor floods has received attention. Studies of debris basins, their use and construction, and of small dams, are yielding information on the use of these structures in water control. Similarly also, the water-spreading work in California is showing how and under what conditions it is possible to utilize floodwaters, usually wasted, to restore depleted ground-water supplies. More recently, the Division has undertaken leadership in the snow surveys in the West as a basis for forecasting the water yields of watersheds. In the field of tillage, studies are being made of type of farm machinery and equipment in relation to conservation practices, and of tillage practices to encourage water conservation.

In the Bureau of Plant Industry research is being continued on the classification, identification, and mapping of soil types, supplemented by physical and chemical studies, and the determination of those properties which influence their capabilities for use. As in the past, this work is cooperative with local State agencies, especially the State agricultural experiment stations. Work is being done in cooperation with other agencies to determine the kinds of fertilizer and other amendments needed by soils to make them suitable for vigorous plant growth.

The work of the Bureau of Plant Industry is concerned chiefly with cultivated plants. Wholly aside from its studies of plant behavior and growth, much of its work on agricultural practices and on soil improvement has direct bearing upon the water-conservation problem. Its studies of soil fertility, humus, and microbiology are supplying almost directly information on plant and water and soil relationships. The introduction of new plants from other countries of value in erosion control has provided additional means of restoring cover on depleted soils. This introduction activity is being supplemented by the breeding of grasses suited for reclaiming overgrazed western ranges.

LITERATURE CITED

(1) Ashe, W. W.
1907. RELATION OF SOILS AND FOREST COVER TO QUALITY AND QUANTITY OF SURFACE WATER IN THE POTOMAC BASIN. U. S. Geol. Survey Water Supply Paper 192: 299–335, illus.

(2) AUTEN, JOHN T.
1933. POROSITY AND WATER ABSORPTION OF FOREST SOILS. Jour. Agr. Res. 46; 997–1014, illus.
(3) BAILEY, REED W.
1935. SHACKLING THE MOUNTAIN FLOODS. Amer. Forests 41: 101–104, illus.
(4) ——— and CONNAUGHTON, CHARLES A.
1936. IN WATERSHED PROTECTION. *In* The Western Range . . ., 74th Cong., 2nd sess., S. Doc. 199, pp. 303–339, illus.
(5) ——— and CROFT, A. R.
1937. CONTOUR-TRENCHES CONTROL FLOODS AND EROSION ON RANGE LANDS. [U. S.] Emergency Conserv. Work Forestry Pub. 4, 22 pp., illus.
(6) ——— FORSLING, C. L., and BECRAFT, R. J.
1934. FLOODS AND ACCELERATED EROSION IN NORTHERN UTAH. U. S. Dept. Agr. Misc. Pub. 196, 21 pp., illus.
(7) BATES, C. J., and HENRY, A. J.
1928. FOREST AND STREAM-FLOW EXPERIMENT AT WAGON WHEEL GAP, COLO. FINAL REPORT ON COMPLETION OF THE SECOND PHASE OF THE EXPERIMENT. U. S. Monthly Weather Rev. Sup. 30, 79 pp., illus.
(8) ——— and ZEASMAN, O. R.
1930. SOIL EROSION—A LOCAL AND NATIONAL PROBLEM. Wis. Agr. Expt. Sta. Res. Bul. 99, 100 pp., illus.
(9) BENNETT, H. H.
1937. MANAGEMENT AND USE OF AGRICULTURAL LANDS, INCLUDING FARM WOODS AND PASTURE. *In* Headwaters Control and Use, a Summary of Fundamental Principles and Their Application in the Conservation and Utilization of Water and Soils Throughout Headwater Areas, papers presented at Upstream Engin. Conf., Washington, D. C., September 22–23, 1936, pp. 120–157, illus.
(10) BLANEY, H. F., TAYLOR, C. A., and YOUNG, A. A.
1930. RAINFALL PENETRATION AND CONSUMPTIVE USE OF WATER IN THE SANTA ANA RIVER VALLEY AND COASTAL PLAIN . . . Calif. Dept. Pub. Works, Div. Water Resources Bul. 33, 162 pp., illus.
(11) BODE, IRVIN T.
1920. RELATION OF THE SMALLER FOREST AREAS IN NON-FORESTED REGIONS TO EVAPORATION AND MOVEMENT OF SOIL WATER. Iowa Acad. Sci. Proc. 27: [137]–157, illus.
(12) BORNEBUSCH, C. H.
1932. DAS TIERLEBEN DER WALDBODEN. Forstwiss. Centbl. 54: 253–266.
(13) BRADFIELD, RICHARD.
1937. SOIL CONSERVATION FROM THE VIEWPOINT OF SOIL PHYSICS. Amer. Soc. Agron. Jour. 29: 85–92.
(14) BRIGGS, LYMAN J., and SHANTZ, H. J.
1914. RELATIVE WATER REQUIREMENT OF PLANTS. Jour. Agr. Res. 3: 1–64.
(15) BROWN, C. B.
1937. RATES OF SILTING IN REPRESENTATIVE RESERVOIRS THROUGHOUT THE UNITED STATES. Natl. Research Council, Amer. Geophys. Union Trans., Ann. Mtg. 18: 554–557.
(16) BRYAN, KIRK.
1915. GROUND WATER FOR IRRIGATION IN THE SACRAMENTO VALLEY, CALIFORNIA. U. S. Geol. Survey Water Supply Paper 375; 49 pp., illus.
(17) BUTOVITSCH, V. VON, and LEHNER, W.
1933. FREILANDUNTERSUCHUNG DER BODENFAUNA UND DEREN BEDUTUNG FÜR DIE FORSTLICHE PRAXIS. Ztschr. f. Forst u. Jagdw. 65: 225–248.
(18) CANNON, SYLVESTER Q., Chairman.
1931. TORRENTIAL FLOODS IN NORTHERN UTAH, 1930. REPORT OF SPECIAL FLOOD COMMISSION. Utah Agr. Expt. Sta. Cir. 92, 51 pp., illus.
(19) CHURCH, J. E., JR.
1912. THE CONSERVATION OF SNOW. ITS DEPENDENCE ON FORESTS AND MOUNTAINS. Sci. Amer. Sup. 74: 152–155, illus.
(20) CRADDOCK, GEORGE W., and PEARSE, C. KENNETH.
1938. SURFACE RUN-OFF AND EROSION ON GRANITIC MOUNTAIN SOILS OF IDAHO AS INFLUENCED BY RANGE COVER, SOIL DISTURBANCE, SLOPE, AND PRECIPITATION INTENSITY. U. S. Dept. Agr. Cir. 482, 24 pp., illus.

(21) Dachnowski-Stokes, A. P.
1935. peatland as a conserver of rainfall and water supplies. Ecology 16: 173–177.
(22) Darwin, Charles.
1882. the formation of vegetable mould through the action of worms, with observations on their habits. 326 pp., illus. New York.
(23) Duley, F. L., and Miller, M. F.
1923. erosion and surface run-off under different soil conditions. Mo. Agr. Expt. Sta. Res. Bul. 63, 50 pp., illus.
(24) Eakin, Henry M.
1936. the twin problem of erosion and flood-control. Natl. Research Council, Amer. Geophys. Union Trans. 17 (pt. 2): 436–439.
(25) ———
1936. silting of reservoirs. U. S. Dept. Agr. Tech. Bul. 524, 142 pp., illus.
(26) Fleming, Walter E., and Baker, Francis E.
1936. a method for estimating populations of larvae of the japanese beetles in the field. Jour. Agr. Res. 53: 319–331, illus.
(27) Forsling, C. L.
1921. a study of the influence of herbaceous plant cover on surface run-off and soil erosion in relation to grazing of the wasatch plateau in utah. U. S. Dept. Agr. Tech. Bul. 220, 72 pp., illus.
(28) Fuller, G. L., and Hendrickson, B. H.
1931. soil survey of elbert county, georgia. U. S. Bur. Chem. and Soils, Ser. 1928, Rpt. 15, 34 pp., illus.
(29) Glenn, Leonidas Chalmers.
1911. denudation and erosion in the southern appalachian region and the monongahela basin. U. S. Geol. Survey Prof. Paper 72, 137 pp., illus.
(30) Griffin, Alfred A.
1918. influence of forests upon the melting of snow in the cascade range. U. S. Monthly Weather Rev. 46: 324–327, illus.
(31) Hilgard, Eug. W.
1860. report on the geology and agriculture of the state of mississippi. 391 pp., illus. Jackson, Miss.
(32) Holzman, B., and Clarke-Hafstad, K.
1937. changes in atmospheric circulation result in floods. Soil Conserv. 2: 254–255, 266, illus.
(33) Hoyt, W. C., and Troxell, H. C.
1932. forests and stream flow. Amer. Soc. Civ. Engin. Proc. 58: 1057–1066. [Also issued in Amer. Soc. Civ. Engin. Trans. 99: 1–111, illus. 1934. Discussion (by letters) by C. G. Bates, J. E. Willoughby, A. L. Sonderegger, J. C. Stevens, Harry F. Blaney (pp. 42–46), Daniel W. Mead, Ralph R. Randell, H. K. Barrows, Donald M. Baker, Ralph A. Smead, George H. Cecil (pp. 63–65), C. W. Sopp, W. P. Rowe, W. C. Lowdermilk, Rhodes E. Rule, Robert E. Kennedy, Herman Stabler, H. S. Gilman, Charles H. Lee, and reply by Hoyt and Troxell, pp. 94–111.]
(34) Jaenicke, Alexander J., and Foerster, Max H.
1915. the influence of a western yellow pine forest on the accumulation and melting of snow. U. S. Monthly Weather Rev. 43: 115–126, illus.
(35) Kiesselbach, T. A.
1916. transpiration as a factor in crop production. Nebr. Agr. Expt. Sta. Res. Bul. 6, 214 pp., illus.
(36) Lowdermilk, W. C.
1936. agricultural land use and flood control. *In* Silcox, F. A., Lowdermilk, W. C., and Cooke, Morris L. The Scientific Aspects of Flood Control . . . Amer. Assoc. Adv. Sci. Occas. Papers 3: 17–39, illus. [Also Supplement to Science, v. 84. 1936.]
(37) Lowe, E. N.
1922. reforestation, soil erosion, and flood control in the yazoo drainage basin. 4th South. Forestry Cong. Proc. 4: 10–11.
(38) McAtee, W. L.
1907. census of four square feet. Science (n. s.) 26: 447–449.

(39) MEGINNIS, H. G.
1935. EFFECT OF COVER ON SURFACE RUN-OFF AND EROSION IN THE LOESSIAL UPLANDS OF MISSISSIPPI. U. S. Dept. Agr. Cir. 347, 16 pp., illus.
(40) MEINZER, OSCAR EDWARD.
1923. THE OCCURRENCE OF GROUND WATER IN THE UNITED STATES. U. S. Geol. Survey Water Supply Paper 489, 321 pp., illus.
(41) MIDDLETON, H. E., SLATER, C. S. and BYERS, H. G.
1934. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT. U. S. Dept. Agr. Tech. Bul. 430, 63 pp., illus.
(42) MILLER, EDWIN C.
1931. PLANT PHYSIOLOGY, WITH REFERENCE TO THE GREEN PLANT. 900 pp., illus. New York and London.
(43) MUNNS, E. N.
1923. EROSION AND FLOOD PROBLEMS IN CALIFORNIA. 165 pp., illus. Sacramento. (Calif. State Bd. Forestry Rpt. to Legislature 1921, on S. Con. Res. 27).
(44) ——— and SIMS, IVAN H., Compilers.
1936. FORESTS IN FLOOD CONTROL. Sup. Report to Committee on Flood Control, House of Representatives. 74th Cong., 2d sess., on H. R. 12517. 70 pp.
(45) MUSGRAVE, G. W. and FREE, G. R.
1936. SOME FACTORS WHICH MODIFY THE RATE AND TOTAL AMOUNT OF INFILTRATION OF FIELD SOILS. Amer. Soc. Agron. Jour. 28: 727–739, illus.
(46) PEARSON, G. A.
1931. FOREST TYPES IN THE SOUTHWEST AS DETERMINED BY CLIMATE AND SOIL. U. S. Dept. Agr. Tech. Bul. 247, 144 pp., illus.
(47) RABER, ORAN.
1937. WATER UTILIZATION BY TREES, WITH SPECIAL REFERENCE TO THE ECONOMIC FOREST SPECIES OF THE NORTH TEMPERATE ZONE. U. S. Dept. Agr. Misc. Pub. 257, 97 pp.
(48) STEWART, G. R.
1933. A STUDY OF SOIL CHANGES ASSOCIATED WITH THE TRANSITION FROM FERTILE HARDWOOD FOREST LAND TO PASTURE TYPES OF DECREASING FERTILITY. Ecol. Monog. 3:
(49) TAYLOR, T. U.
1929. SILTING OF THE LAKE AT AUSTIN, TEXAS. Amer. Soc. Civ. Engin. Trans. 93: [1681]–1735, illus. [Discussion (by letters) by L. M. Lawson, C. H. Eiffert, Oren Reed, Charles Schultz, John B. Hawley, H. F. Robinson, Julian Montgomery, Kirk Bryan, J. C. Stevens, P. A. Welty, Banks McLaurin, R. G. Tyler, E. C. H. Bantel, R. F. Walter, William Jenner Powell, R. I. Meeker (pp. 1731–1733), and T. U. Taylor.]
(50) THORNTHWAITE, C. WARREN.
1937. THE LIFE HISTORY OF RAINSTORMS. Progress Report from the Oklahoma Climatic Research Center. Geogr. Rev. 27: 92–111.
(51) ———
1937. MICROCLIMATIC STUDIES IN OKLAHOMA AND OHIO. Science 86: 100–101.
(52) ———
1937. THE RELIABILITY OF RAINFALL INTENSITY-FREQUENCY DETERMINATIONS. Natl. Research Council, Amer. Geophys. Union Trans. Ann. Mtg. 18: 476–488.
(53) TOWL, R. N.
1924. SILT AND SILTING BASINS ON DRAINAGE WORKS. (Abstract) Engin. News 92: 488–489.
(54) UNITED STATES CONGRESS.
1908. PRELIMINARY REPORT OF THE INLAND WATERWAYS COMMITTEE. 60th Cong., 1st sess., S. Doc. 325, p. 65.
(55) [UNITED STATES] FOREST SERVICE.
1936. THE WESTERN RANGE. Letter from the Secretary of Agriculture transmitting . . . a report on the western range—a great but neglected natural resource. 74th Cong., 2d sess., S. Doc. 199, 620 pp., illus.

(56) [United States] Great Plains Committee.
1936. THE FUTURE OF THE GREAT PLAINS. Report of the Great Plains Committee. 194 pp., illus. [Also issued as 75th Cong., 1st sess., House Doc. 144.]

(57) Weaver, J. E. and Noll, Wm. C.
1935. COMPARISON OF RUN-OFF AND EROSION IN PRAIRIE, PASTURE AND CULTIVATED LAND. Nebr. Univ. Dept. Bot. Contrib. 96, 37 pp., illus. (Nebr. Univ., Nebr. Conserv and Survey Div., Conserv. Dept. Bull. 11).

(58) Zon, Raphael.
1927. FORESTS AND WATER IN THE LIGHT OF SCIENTIFIC INVESTIGATIONS Reprinted . . . from App. V of final report of Natl. Waterways Comm., 1912. 62d Cong., 2d sess., S. Doc. 469, 106 pp., illus.

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